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Development of a Mobile Pneumohydraulic System for Removal of Sediment Deposits in Shaft Wells

Sarkynov Yerbol[1]*, Yakovlev Alexandr[1], Zhakupova Zhanar[1], Auyelbek Yermek[1],
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Abstract: *This paper presents a study of the pneumohydraulic method for the removal of sediment deposits during the cleaning of shaft wells and the development of a mobile experimental unit. The accumulation of sediment in wells significantly reduces their efficiency and requires effective cleaning technologies. The proposed method combines the action of compressed air and water flow to intensify the process of sediment loosening and removal. A mobile unit was designed and prepared for experimental validation. The proposed approach is expected to provide effective cleaning of wells, reduce labor intensity, and improve operational performance compared to conventional methods. The developed system can be applied in rural and livestock water supply systems.*
KEYWORDS*: PNEUMOHYDRAULIC METHOD, SHAFT WELL, SEDIMENT REMOVAL, MOBILE UNIT, LIVESTOCK WATER SUPPLY, RURAL WATER SUPPLY.*

Introduction

The reliable operation of shaft wells plays an important role in ensuring sustainable water supply for rural areas and agricultural systems. However, during long-term operation, significant accumulation of sediment deposits such as silt, sand, and fine soil particles occurs at the bottom of wells. This leads to a decrease in water yield, deterioration of water quality, and increased operational costs [1, 2].

Shaft wells are widely used as a primary source of water supply in livestock farming, where reliable access to clean water is essential for animal productivity, health, and overall farm efficiency.

Traditional methods for cleaning shaft wells, including mechanical removal and manual dredging, are often labor-intensive, time-consuming, and inefficient, especially in deep or hard-to-access wells. In addition, these methods may not ensure complete removal of compacted sediments, which negatively affects the long-term performance of the well [3].

In recent years, increasing attention has been given to the development of innovative technologies for well cleaning that combine efficiency, mobility, and reduced labor requirements. One of the promising approaches is the use of pneumohydraulic methods, which utilize the combined action of compressed air and water flow to intensify the destruction and removal of sediment deposits.

The pneumohydraulic method enables the loosening of dense sediments due to pressure fluctuations and turbulence created by air–water mixtures. This significantly enhances the cleaning process compared to conventional techniques. Moreover, the integration of such methods into mobile units makes it possible to perform cleaning operations directly under field conditions, which is especially important for remote agricultural and livestock regions.

The aim of this study is to investigate the effectiveness of the pneumohydraulic method for removing sediment deposits in shaft wells and to develop a mobile experimental unit capable of improving the efficiency and operational convenience of the cleaning process.

Formulation of the problem

The accumulation of sediment deposits in shaft wells represents a significant technical problem that directly affects the efficiency and reliability of water supply systems in agricultural and rural areas. Over time, the deposition of silt, sand, and fine soil particles leads to a reduction in the effective volume of the well, clogging of water intake zones, and a decrease in water inflow rates [1, 3].

Existing well cleaning methods, such as manual removal of sediments and the use of mechanical devices, are characterized by high labor intensity, low productivity, and limited effectiveness, particularly in cases of compacted or deeply settled deposits. In addition, many traditional methods require partial or complete shutdown of the well and involve significant operational costs.

A major limitation of current technologies is the inability to efficiently break up dense sediment layers and ensure their complete removal without causing damage to well structures. Furthermore, the lack of mobile and universal technical solutions makes it difficult to apply these methods in remote or decentralized agricultural regions [2, 4].

Therefore, there is a need to develop an effective and technologically advanced method for cleaning shaft wells that combines high efficiency of sediment destruction, reliable removal of loosened material, and adaptability to field conditions. The application of a pneumohydraulic approach, based on the combined action of compressed air and water flow, is considered a promising solution to this problem.

The problem addressed in this study is to substantiate and experimentally investigate the effectiveness of the pneumohydraulic method for sediment removal and to develop a mobile unit that ensures efficient, safe, and practical implementation of this technology under real operating conditions [4, 5].

Analysis of recent research and publications

The problem of sediment accumulation in hydraulic structures, including shaft wells, has been widely studied in recent years due to its significant impact on water supply efficiency and system reliability. Various methods for cleaning wells and removing bottom sediments have been proposed, each with specific advantages and limitations.

Traditional mechanical cleaning methods [1, 3], such as manual dredging, bucket systems, and scraper devices, are still commonly used in practice. However, studies indicate that these methods are labor-intensive, inefficient for compacted sediments, and often fail to ensure complete removal of fine particles. In addition, mechanical methods may disturb well structures and increase maintenance costs.

Hydraulic methods [2, 8] based on high-pressure water jets have also been investigated. These methods improve sediment loosening compared to purely mechanical techniques, but their effectiveness is limited when dealing with dense or cohesive deposits. Furthermore, hydraulic cleaning often requires significant water consumption and stationary equipment, reducing its applicability in remote agricultural areas.

Air-lift and pneumatic technologies [4, 7] have gained attention as alternative approaches for sediment removal. These methods use compressed air to create upward flow and transport sediment particles to the surface. Research shows that air-lift systems are effective for removing loose materials, but their performance decreases when dealing with consolidated or heavy sediments.

Recent studies have focused on combined methods that integrate both hydraulic and pneumatic effects [5, 7]. The pneumohydraulic approach enhances the destruction of sediment layers through pressure pulsations, turbulence, and cavitation effects generated by air-water mixtures. This leads to more efficient loosening and transportation of deposits compared to single-phase methods.

Despite the promising results reported in the literature, the application of pneumohydraulic technologies in the cleaning of shaft wells remains insufficiently studied. In particular, there is a

lack of research on the design of mobile units capable of implementing this method under field conditions, as well as experimental validation of their performance.

Therefore, further investigation is required to develop and optimize pneumohydraulic systems for practical use in agricultural water supply infrastructure.

Materials and Methods

The study of the pneumohydraulic method for cleaning shaft wells is based on a proposed experimental approach that combines theoretical analysis and the planned testing of a mobile unit currently under development.

The pneumohydraulic method is based on the combined action of compressed air and water flow supplied into the lower part of the well. The interaction of these two phases creates a turbulent air-water mixture, which generates pulsating pressure and upward flow [7]. This process is expected to lead to the loosening of compacted sediment layers and the subsequent transportation of particles to the surface.

The experimental setup is intended to include a mobile pneumohydraulic unit consisting of the following main components: a compressor for generating compressed air, a water pump for supplying water under pressure, a mixing chamber, flexible pipelines, and a discharge system for removing the sediment-water mixture. The unit will be mounted on a mobile platform, allowing operation under field conditions.

During the planned experiments, compressed air will be supplied through a pipeline to the lower zone of the well, where it will interact with the incoming water flow. The resulting air-water mixture is expected to create intensive turbulence and pressure fluctuations, which will contribute to the destruction of sediment structures. The loosened particles will be transported upward through the well shaft and removed to the surface.

The effectiveness of the method will be evaluated based on several parameters, including the rate of sediment removal, the degree of cleaning of the well bottom, and the energy consumption of the system. Experimental observations are planned to be carried out under different operating conditions, varying air pressure, water flow rate, and duration of the cleaning process.

The obtained data will be analyzed to determine the optimal operating modes of the pneumohydraulic system and to assess its performance compared to traditional cleaning methods.

Design of the mobile unit

The developed mobile pneumohydraulic unit is designed to perform efficient cleaning of shaft wells from sediment deposits under field conditions. The main objective of the design is to ensure high efficiency of sediment removal while maintaining mobility, simplicity of operation, and adaptability to various well conditions.

The structural layout of the unit includes several interconnected components forming a functional system [9,10]. The primary elements of the installation are: a compressor for generating compressed air, a water pump for supplying pressurized water, a mixing chamber, pipelines for fluid and air delivery, and a discharge system for removing the sediment-water mixture.

The compressor provides a continuous supply of compressed air into the system, which is directed through a pipeline to the lower part of the well. Simultaneously, the water pump delivers water under pressure into the mixing chamber. In this chamber, air and water interact to form a two-phase flow characterized by high turbulence and pulsating pressure.

The velocity of the air–water mixture in the pipeline can be estimated as:

$$v = \frac{Q}{A} \quad (1)$$

where v is the flow velocity (m/s), Q is the volumetric flow rate of the mixture (m^3/s), and A is the cross-sectional area of the pipeline (m^2).

The density of the air–water mixture can be expressed as:

$$\rho_{mix} = \alpha\rho_{air} + (1-\alpha)\rho_{water} \quad (2)$$

where ρ_{mix} is the density of the mixture, α is the volumetric fraction of air, ρ_{air} is the density of air, and ρ_{water} is the density of water.

The generated air–water mixture is injected into the bottom zone of the well, where sediment deposits are accumulated. Due to the combined effect of hydraulic and pneumatic forces, dense sediment layers are loosened and transformed into a suspended state. The lifting force acting on the mixture can be estimated as:

$$F = \rho_{mix}\, gH \quad (3)$$

where F is the lifting force, g is the gravitational acceleration (9.81 m/s^2), and H is the depth of the well.

The resulting mixture of water, air, and sediment particles is then transported upward through the well shaft [9]. The removal of the sediment-laden mixture is carried out through a discharge pipeline to the surface, where the material can be collected or diverted away from the well.

The entire system is mounted on a mobile platform, which allows transportation between different sites and enables operation in remote agricultural and livestock areas. The proposed design ensures flexibility in operation, as key parameters such as air pressure and water flow rate can be regulated depending on the characteristics of the well and the type of sediment. This adaptability significantly improves the efficiency of the cleaning process and reduces operational time.

Figure 1 illustrates the general schematic of the mobile pneumohydraulic unit and the interaction of its main components during the cleaning process.

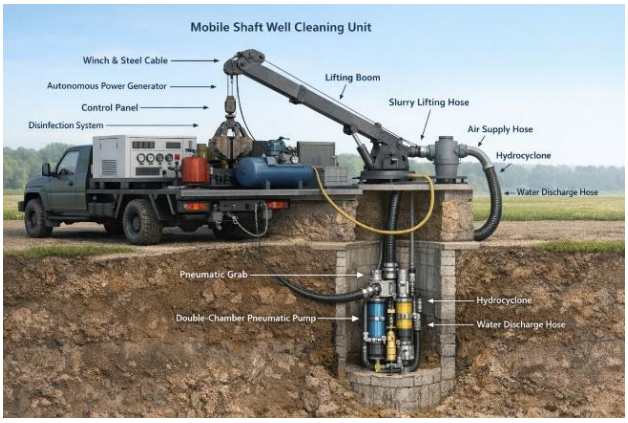


Fig. 1. Schematic diagram of the mobile pneumohydraulic unit

Results and discussions

At the current stage of the research, a pilot shaft well with a depth of 30 m located in the Almaty region has been prepared for experimental studies. The well is intended to be used as a testing site for evaluating the performance of the developed mobile pneumohydraulic unit.

Since the experimental unit is still under development and assembly, full-scale field experiments have not yet been conducted. Therefore, the present study focuses on the analysis of the expected performance characteristics of the pneumohydraulic method based on theoretical considerations and preliminary design parameters.

The efficiency of the proposed method is primarily associated with the generation of a turbulent air–water flow in the lower zone of the well. The interaction of compressed air and pressurized water is expected to create intensive mixing, pressure pulsations, and upward flow, which contribute to the loosening and lifting of sediment particles [8].

The expected operating parameters of the developed system are presented in Table 1.

Table 1. Expected operating parameters of the pneumohydraulic system

Parameter	Value
Well depth	30 m
Air pressure	0.3 – 0.6 MPa
Water flow rate	1 – 3 L/s
Estimated mixture velocity	1.5 – 3.0 m/s
Cleaning duration	1 – 2 hours

The presented parameters are consistent with similar studies of pneumatic and hydraulic systems [8, 11]. Recent studies also confirm the effectiveness of combined hydraulic and pneumatic approaches in water systems [6].

These results indicate the potential efficiency of the pneumohydraulic method for sediment removal under the given operating conditions.

Based on the design of the system, it is assumed that the pneumohydraulic method will provide more effective sedimen destruction compared to traditional mechanical cleaning techniques In particular, the combined action of pneumatic and hydraulic force is expected to improve the removal of compacted deposits and reduce the time required for well cleaning.

The mobility of the developed unit is another important advantage. The ability to transport the system to different locations allows its application in rural and livestock water supply systems where stationary equipment is not available.

Future experimental studies will be carried out on the prepared well to determine key operational parameters, including optimal air pressure, water flow rate, sediment removal efficiency, and energy consumption. The obtained results will allow further optimization of the system and validation of the proposed method under real operating conditions.

The proposed method is expected to reduce cleaning time by approximately 25–40% compared to traditional methods.

Conclusions

The study addresses the problem of sediment accumulation in shaft wells and proposes a pneumohydraulic method as an effective solution for improving the cleaning process. The analysis of existing methods has shown that traditional mechanical and hydraulic techniques have significant limitations in terms of efficiency, labor intensity, and applicability under field conditions.

The proposed pneumohydraulic approach, based on the combined action of compressed air and water flow, is expected to significantly enhance the process of sediment loosening and removal. The interaction of air and water creates turbulence and pressure fluctuations that contribute to the destruction of compacted deposits and their transportation to the surface.

A mobile pneumohydraulic unit has been designed, ensuring operational flexibility and applicability in remote rural and livestock water supply systems. The use of a mobile platform allows the system to be easily transported and deployed under various field conditions.

At the current stage, a pilot shaft well with a depth of 30 m in the Almaty region has been prepared for experimental validation of the proposed method. Although full-scale experimental results are not yet available, the theoretical analysis and design considerations indicate the high potential effectiveness of the developed system.

Future research will focus on experimental testing of the mobile unit, determination of optimal operating parameters, and quantitative evaluation of sediment removal efficiency. The results of these studies will allow further improvement of the system and confirm its practical applicability in rural and livestock water supply systems.

Acknowledgements

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Justification of the design parameters for a flexible screw conveyor system for the disposal of damaged soil from blast craters

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Abstract. This article presents the design of a device with a flexible screw conveyor that will improve the functional and operational characteristics of screw conveyors during the disposal of excavated contaminated soil. To select optimal design parameters for the sections of the screw working element, computer modeling was performed to assess the impact of force loads on corresponding deformations depending on operating conditions.

KEYWORDS: *AGRICULTURAL SOILS, CONTAMINATION, TRANSPORTATION, FLEXIBLE SCREW CONVEYOR, SCREW*

Introduction

As a result of military operations, thousands of hectares of Ukrainian land are suffering significant destruction, bombing, deterioration in quality, and intensified degradation processes, leading to a range of mechanical, physical, and chemical impacts on the soil cover. Such impacts lead to the destruction of the structure and functions of the soil ecosystem and result in the deterioration of its physico-geochemical properties.

Enemy aviation and artillery have the greatest impact on agricultural land and the soil cover, accounting for about 80% of the damage. As a result of rocket and artillery shelling, fields are covered with craters (impact holes) from the explosions of shells, mines, and rockets. The craters vary in diameter and depth [1].

Therefore, transforming contaminated land into usable areas and preserving the fertility of agricultural soils is a pressing issue for ensuring Ukraine's food security.

To restore areas damaged by explosions, it is necessary to remove or clear the topsoil, since, in addition to chemical contamination with heavy metals, the fertile soil layer is also depleted. To carry out technical reclamation of land damaged by bombing, a method is proposed that involves first clearing craters of soil damaged and contaminated by heavy metals and other hazardous substances. To dispose of the removed contaminated soil layer, a flexible screw conveyor with a sectional screw working element can be used, which will enable it to be transferred into a truck bed.

Since screw conveyors are most widely used for transporting various types of bulk agricultural materials, including grains, granulated seed materials, clay, sand, loose soil, compound feed, mineral fertilizer granules, and others.

After all, the foundation of comprehensive mechanization of loading and unloading operations, which increase labor productivity and production efficiency, lies in technical means for the continuous transport of loose agricultural materials. The transport of grain and seed materials along straight, curved, and combined routes using flexible screw working elements enclosed in elastic casings ensures high productivity and mobility during the execution of various technological processes, thereby expanding their technological capabilities and reducing energy consumption.

The main drawback of rigid screw conveyors is the limited mobility of the process lines. Furthermore, the placement of the screw shaft in supports and a rigid guide tube leads to increased material consumption in the construction of such conveyors [2, 3].

Based on the analysis of the literature, it can be concluded that the least resource-intensive technology for conveying bulk agricultural materials along curved routes is the use of flexible screw conveyors, which are constructed from separate screw sections hinged together [4, 5]. In [6–8], the structural, kinematic, and technological parameters of screw working elements are substantiated in terms of their functional purpose.

To address these shortcomings, active research has recently been conducted to develop optimal designs for flexible screw conveyors with enhanced functional and operational characteristics [9, 10]. In such conveyors, the flexible screw working element is freely (without supports) located within an elastic casing and moves the material to the discharge zone via its inner surface, which is their main advantage.

Rotating at a frequency of over 550 rpm, the flexible screw spiral effectively distributes the bulk material evenly along the periphery of the conveyor casing, which causes it to self-center and ensures the movement of the product to the discharge zone [11, 12].

Based on the results of the conducted studies, the structural, kinematic, and technological parameters of the working elements of a flexible screw conveyor have been substantiated in terms of their functional purpose [13, 14]. At the same time, a number of issues regarding the operational and service life characteristics of such working elements remain unresolved. This indicates that improving the operational efficiency of flexible screw conveyors is an important and pressing task in agricultural production.

Therefore, the task of developing new designs and justifying the parameters of flexible screw working elements that will ensure an improvement in the functional and operational performance of conveyors is of great relevance

Results and Discussion

To improve the functional and operational performance of screw conveyors when transporting cleared, damaged soil, a device design with a flexible screw conveyor was developed; its structural diagram is shown in Fig. 1. This device consists of a frame 1, which contains a loading 2 and unloading 3 flexible lines, consisting of fixed casings and sectional screws. Moreover, the casing of the loading line 2 has an opening 4 on one side for self-loading of soil, and the casing of the unloading line 3 has an opening 5 for unloading it; on the other side, the casings are connected to the drive shafts of the transfer pipe 6. Coaxial with the flexible ducts of the lines on the opposite side of the transfer pipe 6, the shafts of the sectional screw working elements are kinematically connected to the intermediate shaft 7 via chain drives. The lower 8 and upper 9 brackets are mounted on the housing of the transfer pipe 6, by means of which the conveyor is connected to the central and longitudinal links of the hitch system of the machine-tractor unit. During operation, the kinematically connected drive shafts of the screw working elements, the intermediate shaft, and the power take-off shaft of the machine-tractor unit ensure the rotation of the flexible sectional screw.

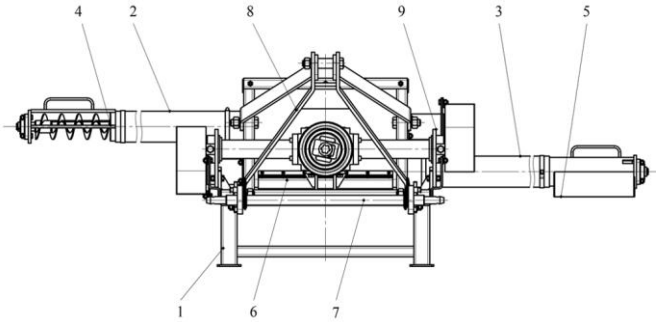


Figure 1*. Design and process diagram of a device for transporting scraped damaged soil:*
1 – frame; 2 – loading line; 3 – unloading line; 4 – self-loading opening; 5 – unloading opening; 6 – transfer pipe; 7 – intermediate shaft; 8 – lower bracket; 9 – upper bracket

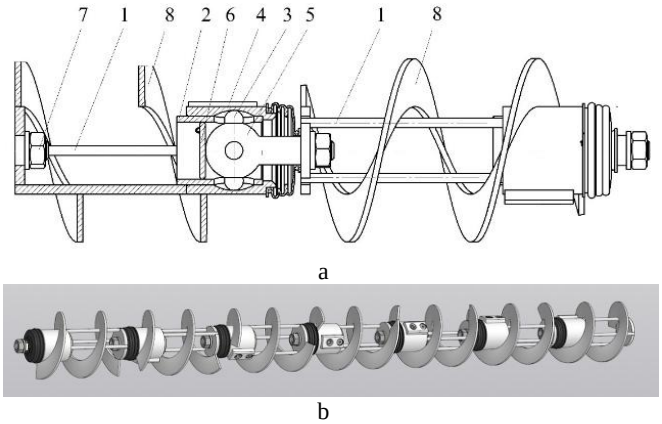
To transport scraped damaged soil, the loading line with a flexible sectional screw is placed inside the pit. The conveyor screw picks up the excavated soil through the self-loading opening and, as a result of the screw's rotation, transports it in a stationary flexible casing toward the conveyor's transfer pipe and, via the unloading line with a sectional screw, to the unloading zone into the body of the machine-tractor unit.

Figure 2 shows a general view of the device with a flexible screw conveyor for transporting excavated damaged soil.



***Figure 2**. General view of the device with a flexible screw conveyor for transporting cleared damaged soil*

Figure 3 presents a structural diagram of such a sectional screw conveyor. It consists of separate sections of identical diameters and lengths, which are constructed as welded structures containing rods 1, to one end of which a cylindrical sleeve 2 is rigidly attached, which is designed with a system of axial parallel grooves evenly spaced around the circumference, interacting with balls 3. On the other side, the balls 3 interact with spherical recesses in the housing 4, enabling axial and angular rotation of the spherical pin 5.



a

b

***Figure 3.** Schematic diagram (a) and 3D model (b) of a sectional screw*

In addition, at the top, the cylindrical sleeve 2 is in rigid contact with the spherical housing 4, the inner surface of which interacts with the outer surfaces of the balls 3, At the other end of the welded cylindrical section, a connecting sleeve 6 is rigidly installed in the inner bore, perpendicular to the axis, which interacts with the corresponding end of the spherical pin 5 of the adjacent section and rigidly secures it via a bolted connection 7. A screw section 8 is rigidly welded to the outer diameter of the cylindrical section.

The screw operates as follows. During the rotation of the spiral section 8, the rotational motion is transmitted through the balls 3 to the spherical pin 5 and the adjacent sections of the screw working element**.**

To select optimal design parameters for the screw sections, computer modeling was performed to analyze the effect of force loads on corresponding deformations depending on operating conditions. Using a software package, a computer model of a screw section of a device with a flexible screw conveyor and hinged transmission mechanisms fixed within it was created (Fig. 4).

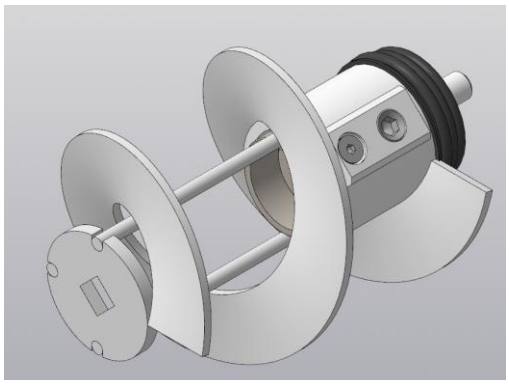


***Figure 4**. Section model for calculating the section twist angle φ*

To calculate the section twist angle φ and obtain the corresponding graphical dependencies on the torque, the experimental conditions were simulated. One intermediate element was rigidly fixed, while a torque was applied to the other. Three parameters were varied: the number of section base rods n; the thickness of the section's helical spiral δ; and the applied torque T.

In the SolidWorks program on a PC, we generated a graphical representation of the movement of the working body's components under the action of an applied torque. Based on the obtained values, we calculated the twist angle φ of the section as a function of the number of rods n, the thickness δ of the section's helical spiral, and the applied torque T. The resulting graphical dependencies are shown in Figs. 5 and 6. Analysis of these curves shows that the section twist angle increases with increasing torque. The most significant increase is observed for n = 2 axial rods in the section base, and the smallest for δ = 4 mm.

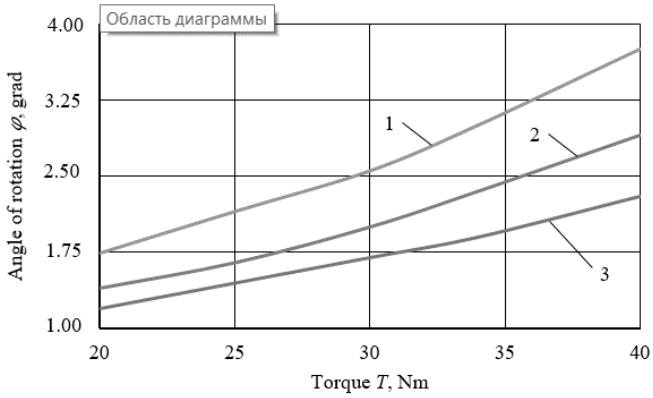


***Figure 5.** Dependence of the section twist angle φ on the number of rods: 1 — n = 2; 2 — n = 3; 3 — n = 4*

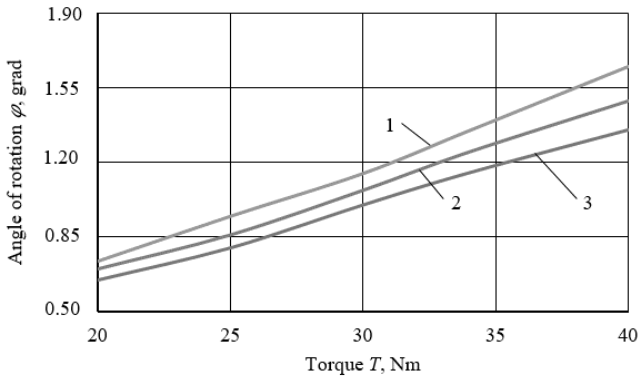


***Figure 6.** Dependence of the section twist angle φ on the thickness of the screw spiral: 1 — δ = 2 mm; 2 — δ = 3 mm; 3 — δ = 4 mm*

Thus, the theoretical studies conducted provide grounds for asserting that the newly developed design of a device with a flexible screw conveyor makes it possible to improve operational efficiency and expands technological capabilities during the transportation of bulk agricultural materials, in particular, cleared or damaged soil.

Conclusions

1. Thousands of hectares of land were bombed during the war. Military operations lead not only to mechanical and physical deterioration of the soil but also to its chemical contamination. To restore areas damaged by explosions, it is necessary to remove or clear the topsoil layer, since, in addition to chemical contamination with heavy metals, the fertile soil layer is also depleted. To carry out technical reclamation of land damaged by bombing, a method is proposed that involves first clearing the craters of soil damaged and contaminated by heavy metals and other hazardous substances. To dispose of the removed contaminated soil layer, a flexible screw conveyor with a sectional screw working element can be used, which will enable it to be transferred into a truck bed.

2. A design of a device with a flexible screw conveyor is presented, which will improve the functional and operational characteristics of screw conveyors during the disposal of the removed contaminated soil layer.

2. To select optimal design parameters for the sections of the screw working element, computer simulations were conducted to analyze the effect of force loads on corresponding deformations depending on operating conditions.

3. Based on the plotted graphical dependencies of the section twist angle as a function of the number of rods, the thickness of the screw helix, and the applied torque values, it was established that the twist angle of the sections increases with an increase in torque. The most significant increase is observed for the number of axial rods in the section base $n = 2$, and the smallest for $\delta = 4$ mm.

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Enhancing the Drying Efficiency and Quality Preservation of Medicinal and Aromatic Plants through Innovative Solar Drying Systems in Albania.

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Abstract: *Albania has a long tradition in the collecting, cultivation and export of medicinal and aromatic plants (MAPs), with more than 400 wild species of economic importance, representing nearly 15% of the country's flora. Drying is a key post-harvest process that affects moisture reduction, microbial stability, and preservation of bioactive compounds, essential oils, color, and overall product quality. This study evaluates innovative solar-powered drying systems for medicinal and aromatic plants and mountain fruits in Bilisht and Ersekë, Albania. Data collected from March to August 2023 included fresh biomass weight, layer thickness, biomass density, drying temperature and duration, relative humidity, ambient temperature, and final dry biomass. The systems incorporated heat-absorbing materials and transparent covers to improve solar energy capture and airflow control. Drying temperature and duration were identified as the main factors affecting the physical, microbiological, and phytochemical quality of dried products. Results showed that solar drying systems reduced drying time and improved product quality compared with traditional drying methods. These findings suggest that innovative solar drying systems can improve energy efficiency, preserve product quality, and increase the commercial value of medicinal and aromatic plants in Albania.*
KEYWORDS: *MEDICINAL AND AROMATIC PLANTS, SOLAR DRYING, DRYING EFFICIENCY, ALBANIA*

1. Introduction

Albania is endowed with exceptional botanical biodiversity, hosting more than 3,200 vascular plant species, of which over 400 species of medicinal and aromatic plants (MAPs) hold significant economic importance, representing approximately 15% of the national flora [1,2,3]. The country's pronounced altitudinal gradient — from Mediterranean coastal zones to alpine massifs exceeding 2,500 m generates a mosaic of microclimatic conditions that sustain a rich and diverse MAP flora. Species of major commercial importance include *Salvia officinalis* (sage), *Origanum vulgare* (oregano), *Thymus* spp. (thyme), *Melissa officinalis* (lemon balm), *Hypericum perforatum* (St. John's wort), *Lavandula angustifolia* (lavender), *Mentha* spp. (mints), and *Gentiana lutea* (yellow gentian), among many others.

The MAP sector provides critical livelihood support to an estimated 50,000–70,000 rural and mountain families in Albania, often constituting a primary or supplementary income source [1, 4, 5, 6]. Albania ranks among the leading MAP exporters in the Western Balkans, with annual export volumes reaching several thousand tons and generating multi-million-euro revenues. Principal export destinations include Germany, France, Italy, and other European Union member states, where demand for high-quality, certified organic plant material continues to expand.

Drying is the most critical post-harvest operation for MAPs, directly determining moisture content reduction, microbial stability, preservation of bioactive compounds, volatile essential oil retention, color integrity, and overall commercial quality [7, 8, 9]. Inadequate drying practices produce substantial qualitative and quantitative losses, compromising product marketability and compliance with European pharmacopoeia and food safety standards. The European Pharmacopoeia 10.0 and European Medicines Agency (EMA) guidelines specify that drying temperatures should remain within 35–45°C for most aromatic species and below 40°C for volatile oil-rich plants [10, 11].

Traditional drying methods prevalent in Albania — including open-air sun drying on ground mats, shade drying under rudimentary canopies, and attic drying offer minimal control over temperature, relative humidity, and airflow. These methods result in heterogeneous moisture distribution, prolonged drying periods of 5–15 days, and elevated risks of microbial contamination by aflatoxin-producing molds [12, 11]. Moreover, direct exposure to solar radiation promotes photo degradation of chlorophylls, carotenoids, and phenolic compounds, causing colour deterioration and reduced antioxidant capacity [13]. Surface temperatures on traditional drying mats may exceed 60–70°C during summer months, far surpassing internationally recommended thresholds and causing irreversible essential oil volatilization and thermo labile compound degradation.

Solar drying technology represents a cost-effective, environmentally sustainable alternative capable of overcoming these limitations. Modern solar dryers create a controlled thermal microenvironment through transparent covers and heat-absorbing surfaces, accelerating moisture evaporation while protecting plant material from direct UV radiation, dust, insects, and rainfall [14, 15]. The incorporation of photovoltaic-powered ventilation fans enables active airflow regulation without grid electricity dependency, a critical advantage for remote Albanian mountain communities. Recent advances in low-cost photovoltaic systems have substantially improved the economic accessibility of solar drying technologies for smallholder MAP producers [16, 17].

The mathematical modelling of drying kinetics through established thin-layer drying models including the Page, Henderson and Pabis, and Midilli–Kucuk models has become an important tool for understanding moisture transfer dynamics and optimizing solar drying system design [18, 19]. Despite extensive global literature on solar drying of food and agricultural products, scientific investigations specifically addressing MAP drying under Western Balkan and Albanian agroecological conditions remain limited. This knowledge gap inhibits evidence-based technology adoption and policy development in the sector.

The present study addresses this gap by comprehensively evaluating two innovative solar drying systems a flat-bed solar dryer in Bilisht (Devoll Municipality, southeastern Albania) and a tunnel solar dryer in Ersekë (Kolonjë Municipality) over the monitoring period March–September 2023. The study objectives were to: (i) characterize the thermal performance and drying kinetics of both systems; (ii) quantify their effects on physical, microbiological, and phytochemical product quality; (iii) compare performance with traditional drying practices; and (iv) provide evidence-based recommendations for the strategic up scaling of solar drying technology in Albanian MAP-producing mountain regions.

2. Materials and Methods

2.1 Study Areas

The study was conducted in two MAP producing areas of southeastern Albania: Bilisht (870–925 m a.s.l.) and Ersekë (1,040–1,050 m a.s.l.). Both sites are characterized by continental climate conditions with Mediterranean influences, including dry summers, cold winters, and high solar irradiance during the vegetation period. During March–September 2023, mean solar irradiance ranged from 5.2–6.4 kWh m^{-2} day^{-1} in Bilisht and 4.8–5.9 kWh m^{-2} day^{-1} in Ersekë.

2.2 Solar Drying Systems

A flat-bed solar dryer was installed in Bilisht and a tunnel solar dryer in Ersekë. Both systems were equipped with photovoltaic-powered DC ventilation fans and covered with transparent solar-transmitting materials to enhance heat accumulation and airflow. The flat-bed dryer had a larger processing capacity (up to 850 kg fresh biomass per cycle), while the tunnel dryer processed up to 180 kg per cycle and provided improved thermal uniformity. Temperature and relative humidity were continuously monitored during operation.

2.3 Plant Material

The monitored species included *Salvia officinalis*, *Origanum vulgare*, *Thymus serpyllum*, *Melissa officinalis*, *Hypericum perforatum*, *Mentha longifolia*, *Rosa canina*, and *Sambucus nigra*. Plant material was harvested at the beginning of flowering and transported to drying facilities within 4–6 h after harvest.

2.4 Statistical Analysis

Data were analyzed using IBM SPSS Statistics v27.0 and Microsoft Excel 2019. Descriptive statistics, t-tests, one-way ANOVA, and Pearson correlation analysis were applied. Statistical significance was accepted at $p < 0.05$.

3. Results

3.1 Thermal Performance and Relative Humidity

The flat-bed solar dryer (Bilisht) achieved a mean internal temperature of 42.3 ± 3.8°C, representing a thermal elevation of 14.7°C above ambient. The tunnel dryer (Ersekë) recorded lower values (38.7 ± 2.5°C), attributable to its higher altitude (1,040 m) and reduced thermal mass. Internal relative humidity was maintained substantially below ambient in both systems (28.4% and 32.1%, respectively), compared with 44–65% under traditional open-air drying. The tunnel dryer demonstrated superior thermal spatial uniformity (±2.5°C vs. ±3.8°C), with positive implications for product homogeneity.

Both systems achieved drying time reductions of 84–88% relative to traditional drying (herbs: 18.4 h vs. 144–240 h; fruits: 28.7 h vs. 240–360 h). The Midilli-Kucuk model provided the best fit for moisture ratio dynamics in both systems ($R^2 > 0.994$). Effective moisture diffusivity was higher in the flat-bed system, consistent with its greater PV-powered fan capacity (4 × 25 W). A strong inverse correlation between temperature and drying duration ($r = -0.82$, $p < 0.001$) confirmed temperature as the principal kinetic driver. A positive correlation between biomass loading density and drying time ($r = +0.67$, $p < 0.01$) underscores the importance of standardized loading protocols (6–8 kg m^{-2} for leafy herbs; 8–10 kg m^{-2} for fruits).

Table 1. Key thermal performance and biomass processing parameters

Parameter	Flat-Bed Dryer (Bilisht)	Tunnel Dryer (Ersekë)
Mean internal temperature (°C)	42.3 ± 3.8	38.7 ± 2.5
Mean internal relative humidity (%)	28.4 ± 6.1	32.1 ± 5.4
Thermal spatial uniformity (°C)	±3.8	±2.5
Mean drying time — herbs (h)	18.4 ± 3.2	22.6 ± 4.1
Mean drying time — fruits (h)	28.7 ± 5.1	34.2 ± 6.3
Drying time reduction vs. traditional	87.2%	84.3%
Total fresh biomass processed (kg)	8,995	3,032
Total dry biomass produced (kg)	1,853	619
Mean dry matter yield (%)	20.6 ± 2.4	20.4 ± 2.1

Values expressed as mean ± SD. Dry matter yield difference not statistically significant (independent t-test, $p = 0.67$). Traditional drying reference: mean of ten monitored conventional operations.

3.1 Phytochemical Quality and Commercial Implications

Solar drying systems provided significantly superior preservation of phytochemical constituents across all evaluated species (ANOVA, $p < 0.001$ for all parameters). Essential oil contents in solar-dried samples met European Pharmacopoeia 10.0 minimum thresholds (*Salvia officinalis* ≥ 2.0% v/w).

Superior retention of total phenolic content (TPC) and antioxidant capacity in solar-dried products reflects attenuated thermal and oxidative degradation of rosmarinic acid, carnosic acid, and luteolin derivatives key bioactive constituents of sage and oregano within the enclosed, UV-filtered drying environment. TPC values were statistically comparable between both solar systems (42.3 vs. 43.1 mg GAE/g; $p > 0.05$), confirming adequate thermal control in both configurations.

Table 2. Phytochemical quality indicators — solar-dried vs. traditionally dried MAP products (mean ± SD; different letters indicate significant differences, Tukey HSD, $p < 0.05$)

Quality Indicator	Flat-Bed	Tunnel	Traditional
Salvia off. essential oil (%)	2.31 ± 0.28 a	2.19 ± 0.24 a	1.42 ± 0.31 b
Origanum vulg. essential oil (%)	3.84 ± 0.41 a	3.71 ± 0.38 a	2.93 ± 0.45 b
Salvia off. TPC (mg GAE/g d.w.)	42.3 ± 3.8 a	43.1 ± 4.2 a	31.7 ± 5.1 b
Antioxidant capacity (% DPPH inhib.)	68.4 ± 4.2 a	70.1 ± 3.9 a	52.3 ± 6.8 b

TPC: total phenolic content; GAE: gallic acid equivalents; d.w.: dry weight; DPPH: 2,2-diphenyl-1-picrylhydrazyl. Ph. Eur. 10.0 minima: Salvia off. ≥ 2.0%;

4. Conclusions

Both investigated solar drying systems demonstrate clear technical and economic feasibility for smallholder MAP producers in Albanian mountain communities, delivering: (i) drying time reductions of 84–88%; (ii) phytochemical quality compliant with European Pharmacopoeia 10.0 thresholds; (iii) operational cost savings of 70–75% relative to LPG alternatives. The self-sufficient, renewable energy-based operation of both systems renders them particularly appropriate for remote areas with limited grid access, supporting sustainable MAP value chain development and rural income diversification.

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Study of a working body for clearing damaged soil from inside a crater

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Abstract. This article presents the design of a working body for removing the damaged soil layer inside a crater, which allows for field studies of the process of removing the damaged soil layer from inside a crater formed as a result of explosions. A methodology has been developed for conducting experimental studies of the working body for removing the damaged soil layer from inside a crater.

KEYWORDS: *AGRICULTURAL SOILS, EXCAVATOR, CRATER, WORKING BODY*

Introduction

The agricultural sector of the economy suffers the most devastating impact of military operations, namely: damage to and destruction of the fertile soil layer due to the detonation of various types of explosive devices and the movement of military equipment, as well as contamination with harmful substances contained in explosives and fuel and lubricants, cluttering of agricultural land with destroyed military equipment, remnants of fortifications, wood debris, etc. [1–4]. In fields littered with craters of various diameters and depths caused by explosions, it is impossible to safely perform mechanized agricultural work.

Therefore, transforming contaminated land into usable areas and preserving the fertility of agricultural land is a pressing issue.

To restore the topography of agricultural land, it is necessary to remove or clear the damaged soil layer within the crater, as it is chemically contaminated with heavy metals; additionally, this process leads to the burning and dehydration of the fertile soil layer [5–7].

Therefore, to remove the damaged soil layer inside a crater formed by an explosion, it is proposed to use a new working attachment that attaches to an excavator boom and allows for the mechanization of the cleaning process.

Subsequently, if a hazardous concentration of heavy metals and other hazardous substances is detected on the surface of the crater, the removed contaminated soil layer must be disposed of [8–10].

Afterward, the craters should be backfilled, ensuring the soil surface is leveled. In this way, technical land reclamation can be carried out. Subsequently, it is advisable to implement agrotechnical measures on the specified land plot, including disc harrowing and cultivation, and plowing if necessary [11–13].

In this way, technical land reclamation can be carried out, which involves first clearing the craters of damaged and contaminated soil containing heavy metals and other hazardous substances. Afterward, the craters must be backfilled, i.e., the surface leveled. Subsequently, disc harrowing and cultivation can be performed on this land plot, and plowing if necessary.

Results and Discussion

To study the process of removing the damaged soil layer from the center of a crater formed by explosions, an experimental prototype of a working body was manufactured.

The working body consists of a frame in the form of circles to which channels and angles are welded (Fig. 1.1). The welded structure is reinforced with metal rings along its height. A bracket for attachment to the excavator boom with the ability to rotate is welded to the top of the working body. The working body is secured to the excavator boom using brackets. With the help of a hydraulic system, the working body can rotate at an angle and turn around its own axis. Rotating the working body makes it possible to adjust the angle of inclination of the working body relative to the surface of the pit, the surface layer of which needs to be removed. The flanges of the channels and angles, which are welded to the working body, will make it possible to remove the top layer of the pit surface and thus clear it of damaged, melted soil containing heavy metals and other harmful substances.

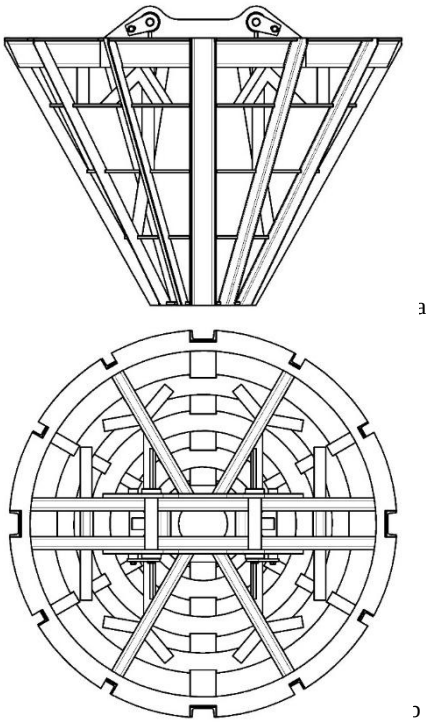


Figure 1*. Schematic diagram of the working body for scraping the damaged soil layer inside the crater: a – front view; b – top view*

This working body is attached to the excavator boom via a hydraulic system. Figure 2 shows a general view of the excavator with the working body installed for removing damaged soil inside craters, as well as a general view of this working body.

The excavator boom consists of a platform to which the boom is attached via a hinged joint. Hydraulic cylinders are attached to the boom, allowing the swing arm to rotate; the working body, in the form of a truncated cone with a hollow inner surface, is attached to the swing arm via a bracket.

Research on the process of removing the damaged soil layer inside the pit was conducted at the experimental field of the Institute of Mechanics and Automation of Agro-Industrial Production of the National Academy of Agrarian Sciences of Ukraine in loamy soil with a moisture content of 10–20% and soil particle cohesion within the range of 0.04–0.06 MPa.

For the dynamic experimental studies, the working body was manufactured with the following parameters: height H = 1 m; upper diameter D = 1.5 m; lower diameter d = 0.4 m. The working elements were channel sections No. 10 GOST 8240-97 and angle irons 45x45x5 GOST 8509-93, in which the flange width is b_{fl}= 46 mm and b_{leg}= 45 mm.

To determine the soil cutting force exerted by the flanges of the channels and angles, an electronic dynamometer with an SBA interface ( ) was used, whose load cell was attached to the brackets of the working body.



***Figure 2**. General view of the excavator with the working body installed for clearing damaged soil inside the pits*

The force indicator is powered by a built-in battery. The permissible error limit of the device is ±5–10 N.

The SBA-500L tensile-compression load cell has a permissible tensile force measurement range of up to 50 kN with a maximum deviation of 0.083 kN.

When the working body, to which the load cell is attached, clears the contaminated surface layer of soil, the electronic dynamometer converts the force into an electrical signal via the tension of the cable; this signal is processed using a corresponding program on a laptop and displayed as an oscillogram on the monitor.

Figure 3 shows the resulting oscillogram of soil cutting force values at a depth equal to the length of the channel or angle iron of the working body, i.e., 45 mm, in loamy soil.

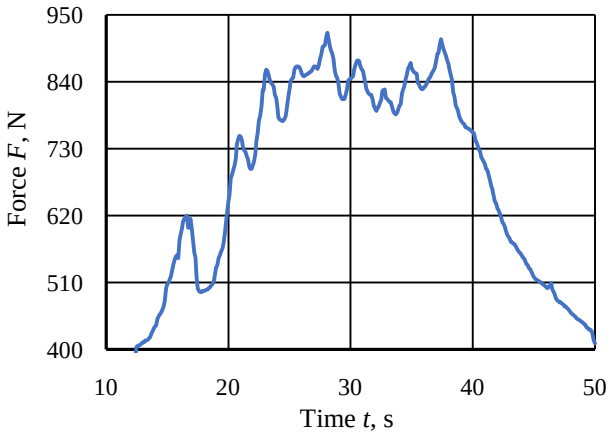


***Figure 3.** Oscillogram of cutting force values for loamy soil*

During the studies, the cutting force values exerted by the flanges of the channels or angles of the developed working body were recorded while removing the surface soil layer in the center of the pit, with ten repetitions.

A comparison of the theoretical calculations presented in [14] and the field experimental studies revealed that the error between the obtained results lies within the range of 4.5–8.6%.

Thus, based on the results of comparative studies, it was established that the preliminary calculation of the soil cutting force exerted by the channel and angle plates of the working body adequately reflects the actual process of scraping the damaged soil layer inside the pit.

Conclusions

The article presents a design diagram of the working body that allows for field studies of the process of removing the damaged soil layer from the center of a crater formed by explosions.

A methodology has been developed for conducting experimental studies of the working body for scraping the damaged soil layer from the center of the crater. Based on a comparison of the theoretical calculations and experimental studies, it was established that the error between the obtained results is within the range of 4.5–8.6%. Thus, based on the results of comparative studies, it was established that the preliminary calculation of the force and energy consumption of soil cutting by the channel sections and angles of the working body adequately reflects the actual process of clearing the damaged soil layer inside the crater.

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New model of agricultural machine for combined soil tillage with increased productivity

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Abstract: *The paper presents a new model of an agricultural machine for combined soil tillage, designed mainly for pre-sowing soil preparation in field crop production and horticulture. The machine combines several technological operations in one pass: cutting and lifting of the untreated soil layer, crushing of soil clods, shredding of plant residues and regulated discharge of the processed material through a grid system. The proposed construction is based on a tractor-mounted implement with two rotating drums equipped with radial hammers, a wedge-shaped comb knife, an intermediate grid, an outlet grid and a rear cover for controlling the size of the processed soil aggregates. The expected increase in productivity is related to the replacement of several consecutive tillage operations with one combined pass, which may reduce field time, fuel consumption, labour input and soil compaction. Since experimental field data are not yet available, the paper also proposes a methodology for future testing, including evaluation of effective field capacity on the machine.*
Keywords*: COMBINED SOIL TILLAGE, AGRICULTURAL MACHINE, PRE-SOWING PREPARATION, PLANT RESIDUES, PRODUCTIVITY*

1. Introduction

Modern agricultural production requires soil tillage machinery that ensures high-quality soil preparation, reduced energy consumption, and a lower number of field passes [1, 2]. In conventional pre-sowing preparation, the soil is often treated through several separate operations, such as ploughing, harrowing, cultivating, and levelling. This approach increases labour input, fuel consumption, and overall operating time [1, 2]. Repeated passes of agricultural machinery also raise the risk of soil compaction and may deteriorate the physical condition of the seedbed [3–5].

The development of combined tillage machines represents an effective approach to improving the efficiency of soil preparation [6, 7]. Such machines are capable of performing multiple technological operations in a single pass, thereby reducing time, fuel consumption, and operational costs. [1, 2] They are particularly suitable for fields containing plant residues, roots, stubble, and leaves, where proper residue management is essential for maintaining soil fertility and structure. [8–10] These residues need to be crushed and incorporated into the soil in order to accelerate their decomposition and enhance the organic matter cycle. [8, 9]

The aim of this paper is to present a new model of an agricultural machine for combined soil tillage with enhanced productivity. The paper describes its construction, operating principle, expected technical advantages, and a methodology for future experimental evaluation.

2. Technical characteristics and Operating principle

- **Technical characteristics of the proposed machine**

The object of the study is a soil tillage machine developed as a utility model BG 1969 U1 “Soil tillage machine”. The machine is intended for pre-sowing soil preparation and can be used in agriculture and horticulture – fig.1. It is attached to a tractor by means of a mounted hitch system, while the active working elements are driven by the tractor power take-off shaft.

The machine body consists of two metal side frames connected by reinforcing beams – fig.2. The body is closed by a front cover, upper cover and rear cover. Two rotating drums are mounted between the side frames. Each drum is supported by bearing units and is equipped with radial hammers – fig.3. The drive system includes a gearbox, cardan shaft, belt pulleys and belt transmissions.

A wedge-shaped comb knife is mounted in the front lower part of the machine – fig.4. Its function is to cut and separate a layer of untreated soil from the ground surface and to direct it towards the first rotating drum. An outlet grid is positioned below the second drum and determines the maximum size of the soil aggregates leaving the machine. An intermediate grid and a reflector are installed between the working elements in order to guide the soil flow and improve the crushing process.

The approximate main dimensions, obtained from the constructive drawings, are:

- working width: about 1.40 m;
- overall length: about 2.32 m;
- type of aggregation: mounted tractor implement;
- main working elements: wedge-shaped comb knife, two rotating drums with radial hammers, intermediate grid, outlet grid and rear cover.

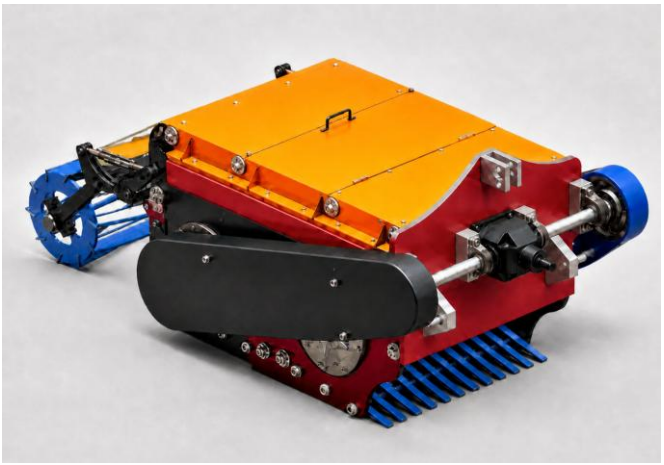


Fig. 1. *General view of the agricultural machine for combined soil tillage.*

- **Operating principle**

During operation, the machine moves forward as part of a tractor-machine aggregate. The wedge-shaped comb knife penetrates the soil, cuts a layer of untreated soil and lifts it towards the first rotating drum. Together with the soil layer, plant residues such as roots, stubble and leaves are also introduced into the working chamber.

The first rotating drum, equipped with radial hammers, breaks the soil clods and starts the shredding of plant residues. The soil mass is then directed towards the second drum, where additional crushing and mixing take place. Larger particles remain longer in the active working zone, while smaller particles pass through the outlet grid. The size of the processed soil aggregates is controlled by the outlet grid and the rear cover.

The complete technological process includes the following operations:

1. cutting of the untreated soil layer;
2. lifting and directing the soil towards the active drums;

3. crushing of soil clods by radial hammers;
4. shredding and mixing of plant residues;
5. regulated discharge of the processed soil through the grid system.

This combined process allows several traditional operations to be replaced by one machine pass. As a result, the total time required for soil preparation can be reduced.

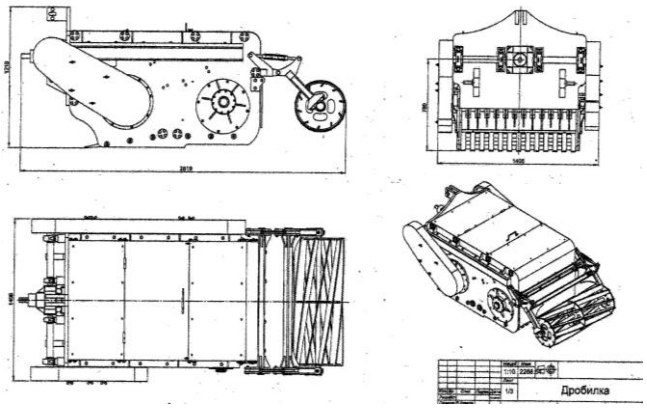


Fig. 2. *Constructive scheme and working elements of the machine.*

- **Expected productivity improvement**

The productivity of a soil tillage machine depends mainly on working width, working speed and the coefficient of field time utilisation. The effective field capacity can be estimated by the following expression:

$$We = 0.1 \cdot B \cdot v \cdot \eta \quad (1)$$

where We is the effective field capacity, ha/h; B is the working width, m; v is the working speed, km/h; and η is the field time utilisation coefficient.

For the proposed machine, when B = 1.40 m, v = 3–5 km/h and η = 0.75–0.85, the expected effective field capacity is approximately 0.32–0.60 ha/h. These values are preliminary and must be verified by field experiments. The final productivity will depend on soil type, soil moisture, working depth, amount of plant residues, tractor power and operating conditions.

The main productivity advantage is not only the theoretical field capacity, but also the reduction in the number of technological passes. Instead of using several machines successively, the proposed model performs cutting, crushing, residue shredding and seedbed preparation in one pass. This can reduce total field time, fuel consumption and labour costs.

- **Planned experimental methodology**

At the current stage of the study, experimental field data have not yet been obtained. The experimental investigation will be carried out at a later stage under real field conditions. The planned tests will include different working speeds, soil moisture levels, working depths and quantities of plant residues.

The following indicators will be measured:

- effective field capacity, ha/h;
- fuel consumption, l/ha;
- working depth and its uniformity;
- soil aggregate size distribution after treatment;
- degree of plant residue shredding;
- tractor wheel slip and load stability;
- number of passes required to obtain a suitable seedbed;
- specific energy consumption.

The experimental results will be compared with a conventional soil preparation technology, including separate tillage operations. This comparison will allow a quantitative assessment of the expected productivity increase and economic efficiency.

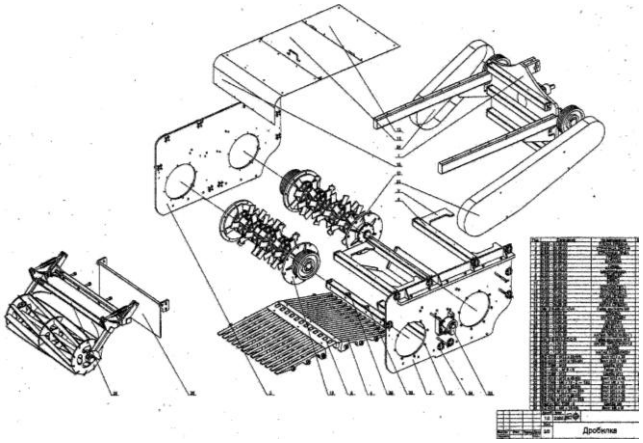


Fig. 3. *Vertical and horizontal sections of the proposed machine.*

- **Advantages of the construction**

The proposed machine has several expected technical and technological advantages.

First, the combination of a wedge-shaped comb knife and two active rotating drums provides intensive soil treatment. The soil layer is not only cut, but also lifted and mechanically processed by radial hammers.

Second, the plant residues are crushed together with the soil. This may accelerate their decomposition and contribute to soil enrichment with organic matter.

Third, the outlet grid improves the uniformity of the processed material by limiting the discharge of large soil clods. This is important for seedbed preparation and for obtaining a more homogeneous soil structure.

Fourth, the use of one combined machine pass can reduce the number of operations, fuel consumption and labour requirements. The lower number of field passes also reduces soil compaction caused by tractor movement.

Finally, the machine has a compact mounted design, which makes it suitable for smaller and medium-sized agricultural fields, as well as for horticultural applications.

The proposed model belongs to the group of active combined tillage machines. In comparison with passive tillage tools, active drums provide more intensive mechanical action on the soil. However, this also requires careful selection of the drum rotation speed, hammer geometry, distance between the knife and the first drum, and size of the grid openings.

Future optimisation should focus on balancing the degree of soil crushing with energy consumption. Excessive crushing can increase power demand and may lead to undesirable pulverisation of the soil, especially under dry conditions. Insufficient crushing, on the other hand, can leave large soil aggregates and poorly shredded plant residues. Therefore, field testing is essential for defining the optimal operating modes.

The machine is especially promising for pre-sowing preparation of soils with a considerable amount of plant residues. By combining several operations in one pass, it can support more efficient use of machinery and more timely field work.

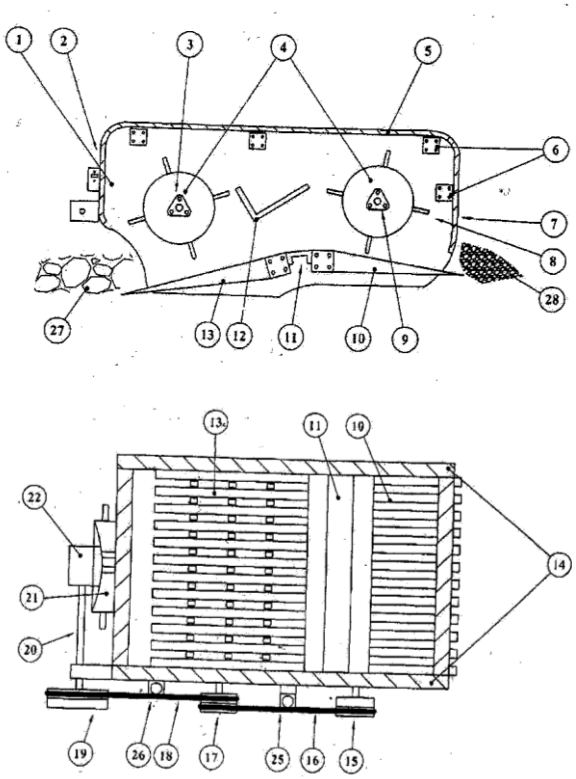


Fig. 4. Wedge-shaped comb knife and grid system.

3. Conclusion

A new model of agricultural machine for combined soil tillage with increased productivity is presented. The machine consists of a mounted frame, wedge-shaped comb knife, two rotating drums with radial hammers, intermediate and outlet grids and a rear cover. The working process combines cutting, lifting, crushing, shredding of plant residues and regulated discharge of the processed soil.

The expected productivity improvement is based on replacing several separate tillage operations with one combined pass. This can reduce operating time, fuel consumption, labour input and soil compaction. Since experimental data are not yet available, field tests will be performed at a later stage to determine the effective field capacity, energy consumption, working quality and economic efficiency of the machine.

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Features of fuel efficiency of tractors, trucks, and passenger cars

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Abstract: *The paper presents the results of studies on the influence of fuel system malfunctions, engine adjustment violations, technical condition, and operating conditions of tractors, trucks, and passenger cars on fuel consumption. The analysis of external speed characteristics of diesel and carburetor engines is carried out. The influence of ignition timing, fuel equipment condition, tire pressure, cooling system operation, and maintenance quality on fuel efficiency indicators is considered. It is shown that untimely maintenance, improper adjustment of engine systems, and violation of operating requirements significantly affect fuel consumption and engine performance. The results of the study demonstrate that the technical condition of vehicles and operating modes are among the main factors determining fuel efficiency indicators.*

KEYWORDS*: TRACTOR, AUTOMOBILES, VEHICLE, ENGINE, FUEL EQUIPMENT, FUEL CONSUMPTION, OPERATING CONDITIONS, MAINTENANCE, REPAIR.*

1. Problem Statement

When conducting comparative studies, it is important to ensure identical operating conditions for the performance of specific tasks by both similar and different types of machines.

In order to investigate the influence of fuel equipment on the performance indicators of a diesel engine, tractor, and machine-tractor unit (MTU) [1,2], one of such conditions was the external speed characteristic of the diesel engine adopted for the study (Table 1, Fig. 1). The variation of four main characteristic parameters was analyzed: effective torque (Me), effective power output (Ne), hourly fuel consumption (Gf), and effective specific fuel consumption (ge). The initial data for calculating the characteristic were selected under the condition of maintaining the structural weight parameters of the tractor and the rated diesel engine power in accordance with the specifications of the production tractor model (m = 7900 kg, Nen = 121.4 kW).

Further analysis of literature sources on this topic revealed that characteristics with a smaller number of key parameters are also used in research practice (Fig. 2). In addition, Fig. 2b demonstrates that the performance indicators of the machine-tractor unit may also depend on other factors, such as tillage depth, soil moisture, and other operating conditions.

Table 1 *– External Speed Characteristic of the SMD-62 Diesel Engine*

№№ п/п	$n_д$, хв$^{-1}$	M_e, Н · м	N_e, кВт	$G_п$, кг/г	g_e, гр /(кВт·г)
1.	1200	624	78,4	21,84	279
2.	1350	687	97,1	25,85	266
3.	1500	693	108,8	28,42	261
4.	1650	672	116,0	29,98	259
5.	1800	635	119,6	30,75	257
6.	1950	595	121,4	31,15	256
7.	2100	554	121,77	29,47	242
8.	2275	0	0	9,5	∞

Source: developed by the authors using data from [3–5].

2. Analysis of Recent Research and Publications

The performance indicators of carburetor engines are also evaluated according to the behavior of their speed characteristics (Fig. 3).

It can be observed that different types of characteristics with varying numbers of investigated parameters are used in research practice. Deviations in the behavior of certain dependencies from generally accepted patterns are also noticeable. For example, at engine speeds below 2500 rpm, the hourly fuel consumption tends to be slightly lower, while the effective specific fuel consumption becomes somewhat higher (Fig. 3a). Similar deviations are observed for the excess air coefficient and effective specific fuel consumption (Fig. 3b) within the low-speed operating range, although the unstable operating mode occurs at higher crankshaft speeds — approximately 4000 rpm compared to 2500 rpm for the previous engine, despite nearly identical rated speed values.

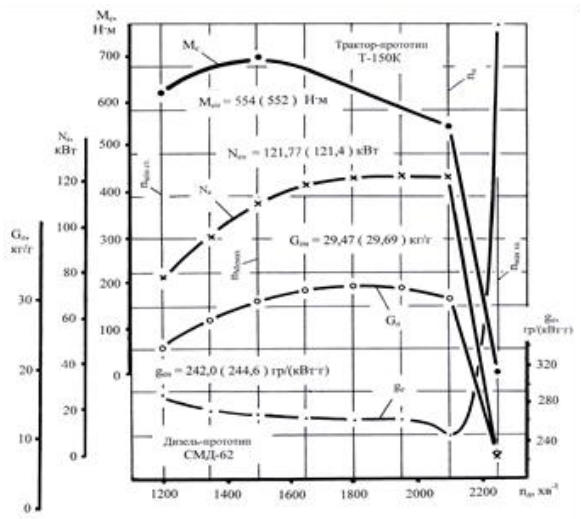
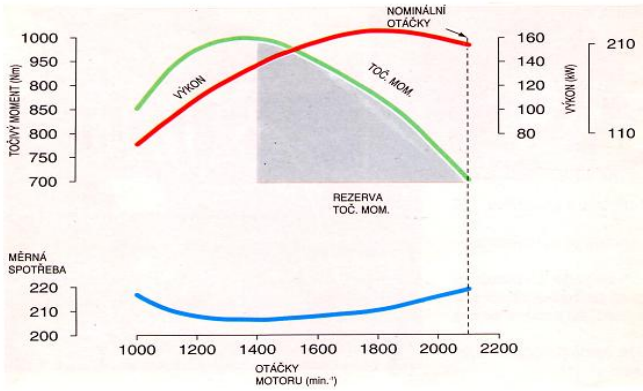
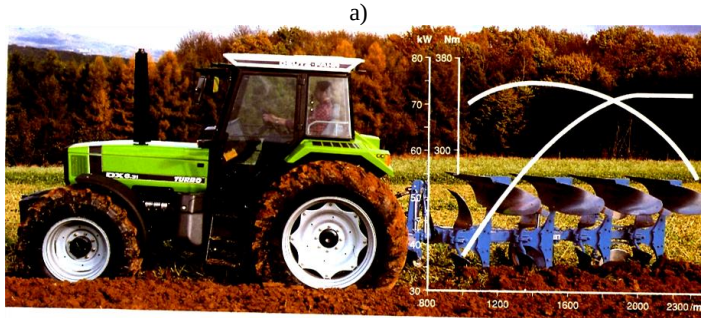


Fig. 1 – External Speed Characteristic of the SMD-62 Diesel Engine

Source: developed by the authors using data from [3–5].



a)



b)

Fig. 2 – General View of External Speed Characteristics of Certain Agricultural Tractors:

a) “Fiatagri” model “Fiat” (Kp = 43%);

b) “Deutz-Fahr” model “AgroStar DX 6.31” (Kp = 36%).

Source: developed by the authors using data from [6,7].

More significant differences in the behavior of the excess air coefficient and effective specific fuel consumption are observed for another engine model (Fig. 3c). These changes become noticeable at engine speeds below 2500 rpm, while the rated engine speed is 3200 rpm.

In addition, the characteristic parameters also depend on the correct selection of the investigated parameter variation range (Fig. 4) and, in particular, on the adjustment parameters of the engine systems (Fig. 5).

Some of the above-mentioned features of the speed characteristics typical of classical carburetor engines operating at low-speed modes are also, to a certain extent, characteristic of modern fuel-injected engines (Fig. 6a, c). Changes in the generally accepted behavior of characteristic dependencies can also be observed at increased crankshaft speeds (Fig. 6b, c). It should be noted that such characteristic behavior patterns do not always change significantly even after engine and vehicle modernization (Fig. 6b).

3. Objectives

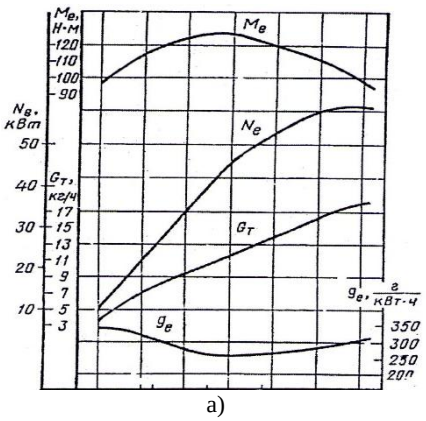
The aim of this study is to identify the causes of increased fuel consumption in locally manufactured vehicles equipped with carburetor engines based on the analysis of their operation under standard operating conditions.

4. Main Material

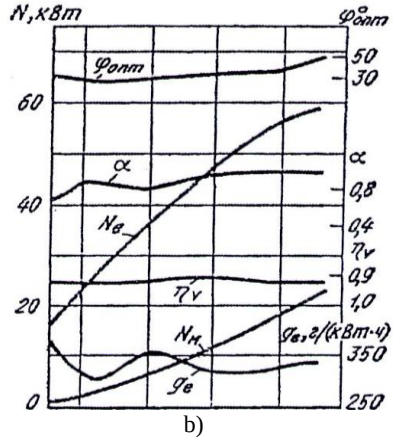
The analysis and preliminary systematization of materials related to this topic began during the preparation of a textbook for publication [12]. The research was further continued while preparing scientific works [8,13–15]. For the purpose of systematization, information from a large number of studies conducted by various authors was used. It is practically impossible to provide a complete list of all such publications and their authors. In our opinion, the most significant studies in this field are presented in references [16–25].

Tables 2–5 present the main indicators reflecting the influence of the technical condition of fuel equipment, vehicle operating conditions, and other factors on the fuel efficiency of vehicles equipped with carburetor engines.

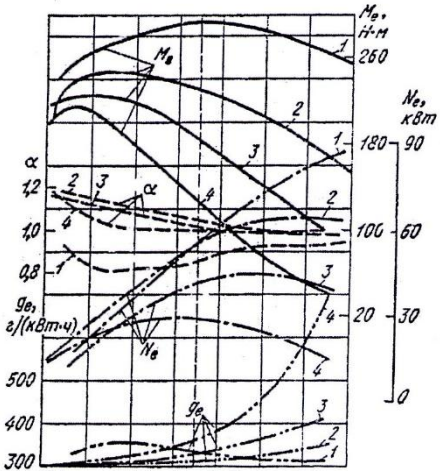
According to the data presented in Table 2, three major influencing factors should be emphasized. First, careless attitude of drivers and engineering personnel (or vehicle owners) toward fuel usage (items 1, 3–6) results in fuel overconsumption of approximately 9.5–12.0%. Second, the level of qualification and responsibility of operators may either lead to additional fuel consumption of 12–14% (item 7) or, conversely, provide fuel savings of 20–30% (item 8). Third, unfavorable operating conditions may increase fuel consumption by 30–400% (item 10).



a)



b)



c)

Fig. 3 – Speed Characteristics of Carburetor Engines:
a) load characteristic (“2106”);
b) external characteristic (“M-412”);
c) external (1) and intermediate (2–4) characteristics of the ZMZ-53 engine (2 – at the limit of effective mixture leaning).
Source: developed by the authors using data from [8].

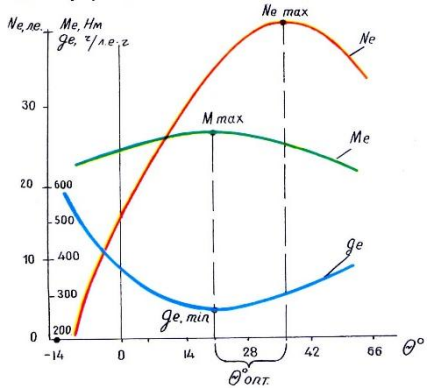


Fig. 4 – Load Characteristic of an Automobile Engine Depending on Ignition Timing Angle θ°
Source: developed by the authors using data from [9].

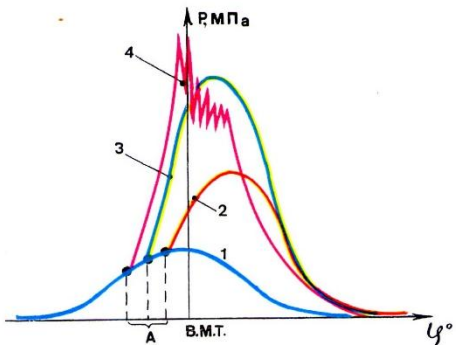


Fig. 5 – Variation of Carburetor Engine Performance Indicators Depending on Component Adjustments:
a) indicator diagrams:
1 – no ignition;
2 – late ignition;
3 – optimum ignition advance angle, normal combustion;
4 – early ignition, detonation combustion.
Source: developed by the authors using data from [9].

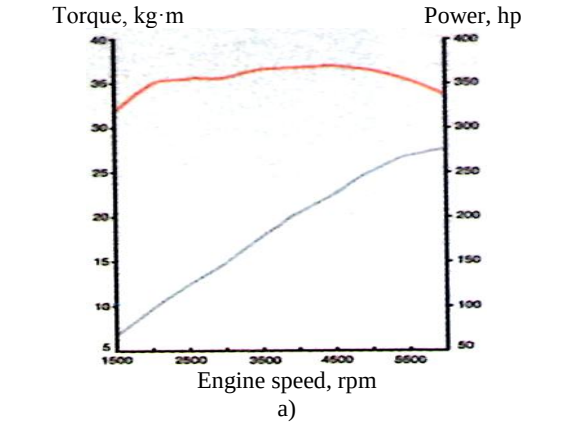


Fig. 6 – External Speed Characteristics of Automobile Engines:
a) Kia Mohave (V6, 3.8 L);
b) Lexus RX 350 (2GR-FE);
c) Formula Renault 3.5 Dallara T12.
Source: developed by the authors using data from [8,10,11].

Table 2 – Influence of Malfunctions and Operating Conditions of Locally Manufactured Vehicles on Fuel Consumption

No.	Malfunction or Operating Condition	Excess Fuel Consumption, %
1	Fuel losses due to overfilling of the fuel tank during refueling	up to 0.5
2	A 1% decrease (increase) in vehicle mass decreases (increases) fuel consumption	~0.5
3	Improper sealing of the fuel tank	1–3
4	Lack of engine warm-up before starting	2
5	Fuel leakage from the fuel tank, pipelines, and other fuel system components	up to 5
6	Fuel losses caused by poor condition and untimely maintenance of fuel storage equipment	3.0–3.5
7	Fuel consumption when driving with the front axle engaged on: asphalt; good road surface	12; 12–14
8	Reduction in fuel consumption by highly qualified drivers	20–25
9	Fuel savings due to driving style and operating modes	>30
10	Increase in fuel consumption when driving on different soil backgrounds compared to asphalt: dry field road; wet road after rain; stubble field	30; 100–200; 400

Source: developed by the authors using data from [13,15–25].

Table 3 – Influence of Malfunctions and Operating Conditions of Locally Manufactured Vehicles on Fuel Consumption

No.	Malfunction or Operating Condition	Excess Fuel Consumption, %
1	Reduction of ignition advance angle by 1°	1
2	Incorrect adjustment of valve thermal clearance	5–7
3	Incorrect front wheel toe adjustment	5–7
4	Use of higher-viscosity oil in transmission units	up to 10
5	Brake lining contact with drums and excessive bearing preload	~10
6	Carbon deposit formation on piston rings and cylinder-piston group	15
7	Diesel injector malfunction	15–20
8	Tire pressure reduction by more than 40%	up to 20
9	Failure of the centrifugal ignition advance mechanism	20
10	Engine operation with coolant temperature of 30–40 °C	30–40
11	Ignition system malfunction	up to 50
12	Inoperative spark plugs (1–2) in a six-cylinder engine	26–60

Source: developed by the authors using data from [13,15–25].

According to the data presented in Table 3, the main influencing factors include the gradual deterioration of the technical condition of the vehicle, which is not detected and eliminated in due time (items 1, 5, 6, 9, 11, 12), as well as untimely technical inspection or absence of proper adjustment and maintenance procedures (items 2, 3, 4, 8, 10, 12). In the first case, fuel consumption increases by 132–156%, while in the second case it increases by 96–144%.

Fuel consumption of passenger cars (Table 4) increases by 74–92% due to deterioration of the technical condition of fuel equipment (items 2, 3, 7, 10, 12), by 26–30% because of carburetor component failures (items 6, 11), by 13–19% due to improper adjustment (items 1, 9), and by 21–25% as a result of violations or failure to comply with operating and maintenance requirements (items 4, 5, 8).

Table 4 – Influence of Malfunctions and Operating Conditions of Locally Passenger Cars on Fuel Consumption

No.	Malfunction or Operating Condition	Excess Fuel Consumption, %
1	Incorrect idle speed adjustment	3–4
2	Wear of accelerator pump drive components	3–5
3	Incorrect economizer operation	4–10
4	Reduction of tire pressure by 0.5–1.0 atm	5–7
5	Engine operation with coolant temperature below 80–90 °C	6–8
6	Failure or malfunction of the vacuum regulator	6–10
7	Reduction of main metering system air jet diameter by 7%	7
8	Clutch slipping due to insufficient pedal free play; oil contamination of clutch friction linings; incorrect wheel alignment; excessive tightening of wheel hub bearings; incorrect brake adjustment or malfunction; low tire pressure	up to 10
9	Improper adjustment of carburetor fuel equipment	10–15
10	Increase in fuel level in the carburetor float chamber by 4 mm above normal	10–20
11	Failure of ignition advance mechanism	20
12	Ignition system malfunction	up to 50

Source: developed by the authors using data from [13,15–25].

Changes in the technical condition of passenger cars (Table 5) (items 1–4, 6–8, 11, 13, 17) increase fuel consumption by 84–129%; improper adjustment (items 2, 5, 10, 12) increases fuel consumption by 28–41%; and violation or non-compliance with operating and maintenance requirements (items 9, 15, 16) leads to an increase of 58–70%.

Table 5 – Influence of Malfunctions and Operating Conditions of Locally Passenger Cars on Fuel Consumption

No.	Malfunction or Operating Condition	Excess Fuel Consumption, %
1	Increase of valve mechanism clearance by 0.1 mm	2
2	Incorrect ignition timing adjustment; engine depressurization caused by damaged seals (blown cylinder head gasket, burned valve edges, loose spark plugs, etc.); reduction of tire pressure by 10–15%	3–4
3	Contaminated air filter	4–5
4	Carbon deposits in the combustion chamber	4–6
5	Incorrect adjustment of thermal clearances and wheel alignment	5–7
6	Increase in carburetor jet diameter	up to 6
7	Increased fuel level in the carburetor float chamber	6–8
8	Scale deposits in the engine cooling system radiator (about 1 mm)	8
9	Engine operation with coolant temperature of 60–70 °C	8–10
10	Incorrect adjustment of the distributor-interrupter; use of higher-viscosity transmission oils	up to 10
11	Leakage of the carburetor economizer valve; reduction of tire pressure by 30–40%	10–15
12	Incorrect adjustment of clutch, wheel bearings, and brakes	10–20
13	Carbon deposits on piston rings and cylinder-piston group	15
14	Diesel injector malfunction	15–20
15	Tire pressure reduction by more than 40%	up to 20
16	Engine operation with coolant temperature of 30–40 °C	30–40
17	Inoperative spark plugs (one or two) in a six-cylinder engine	26–60

Source: developed by the authors using data from [13,15–25].

5. Conclusions

1. Fuel savings during the operation of trucks and passenger cars equipped with carburetor engines may amount to 20–30%.

2. Excess fuel consumption of trucks and passenger cars may vary from 9.5–132% to 12–400%, while for passenger cars it may range from 13–84% to 19–129%.

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Energy consumption of primary tillage operations in conventional and no-till farming systems – a review

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***Abstract**: This article reviews domestic and international literature on the energy consumption of primary tillage operations in four farming systems: conventional (plough-based) tillage, simplified tillage, strip-till and no-till farming. The energy inputs of individual agrotechnical operations were analysed, with particular emphasis on fuel consumption, cumulative energy, CO_2 emissions and the impact on the physical and biological properties of the soil. The results of the review indicate that switching from ploughing to no-till farming reduces fuel consumption by 60–80%, energy inputs by 55–75%, and greenhouse gas emissions by 65–80%. At the same time, no-till systems promote the accumulation of organic matter in the topsoil, improve the stability of soil aggregates and protect against erosion. The limitations of no-till farming under Polish conditions were also discussed, including the risk of seed embedding in heavy soils, problems with weed control, increased reliance on herbicides, and economic and psychological barriers. An economic analysis of cultivation costs in individual systems was carried out for a model farm with an area of 100 ha.*

Keywords: TILLAGE, NO-TILL FARMING, ENERGY INTENSITY, FUEL CONSUMPTION, CO_2 EMISSIONS, DIRECT DRILLING, NO-TILL, STRIP-TILL, CONSERVATION AGRICULTURE

1. Introduction

Tillage is one of the most energy-intensive aspects of crop production, whilst also being a practice of fundamental agrotechnical importance. According to data from the Food and Agriculture Organisation [6], the agricultural sector accounts for approximately 23% of global greenhouse gas emissions, a significant proportion of which is generated by mechanical soil tillage operations. In Poland, where conventional cultivation based on ploughing still predominates, fuel consumption for tillage operations accounts for 35–50% of total fuel consumption on a farm [9]. It is estimated that average diesel consumption in Polish agriculture is approaching 200 litres per hectare of agricultural land per year, of which up to half is attributable to tillage operations [15].

Rising energy costs, tightening environmental regulations under the European Green Deal, the objectives of the 'Farm to Fork' strategy, and the drive towards sustainable agricultural development are prompting a search for alternative technological solutions. No-till farming, also known as direct seeding, is the most radical form of simplifying tillage, involving the complete abandonment of mechanical tillage [19, 32]. According to estimates by Derpsch et al. [5], the area of land cultivated using the no-till method worldwide increased from 45 million ha in 1999 to 111 million ha in 2009, growing at a rate of approximately 6 million ha per year. In Europe, and particularly in Poland, the adoption of these technologies is proceeding more slowly than in South America or Australia, which stems both from the specific soil and climatic conditions and from the structural characteristics of Polish agriculture [10, 24, 25].

In parallel with no-till systems, strip-till technology is developing, combining elements of conservation tillage with spot soil loosening in the root zone . In recent years, strip-till has gained significant popularity among Polish producers of maize, sugar beet and rapeseed, offering a compromise between energy efficiency and optimal plant growth conditions.

The aim of this article is to review and compare the energy consumption of primary tillage operations in conventional technologies and in no-till systems, with particular regard to the conditions of Polish agriculture. The analysis covers fuel consumption, cumulative energy inputs, field productivity, CO_2 emissions, the impact on the physical and biological properties of the soil, as well as the economic aspects associated with the individual cultivation systems.

2. Materials and methods

This paper is a review article. The analysis is based on a critical review of domestic and international literature from 2000 to 2024. The following databases were searched: Web of Science, Scopus, Google Scholar, BazTech and the resources of the National Library, using keywords in English ("tillage energy consumption", "no-till fuel use", "conservation agriculture energy balance", "strip-till energy") and Polish ("energochłonność uprawy roli", "no-till fuel consumption", "direct seeding"). A total of 78 publications meeting the quality criteria were selected – articles from peer-reviewed scientific journals, monographs and reports from research institutes.

Energy data were harmonised into common units. Fuel consumption was expressed in litres of diesel per hectare (l/ha). Energy inputs were converted to megajoules per hectare (MJ/ha), using a conversion factor of 1 l diesel = 35.5 MJ of embodied energy, accounting for the energy required for fuel production, transport and distribution [8]. CO_2 emissions were calculated using a factor of 2.67 kg CO_2 per litre of diesel fuel burned, in accordance with IPCC guidelines [11]. The working resistance of the implements is given in kilonewtons per metre of working width (kN/m).

The economic analysis assumed a diesel price of PLN 6.50/l (as of mid-2024) and average market prices for plant protection products and machinery services according to the price lists of Agricultural Advisory Centres.

3. Energy requirements of conventional cultivation

3.1. Characteristics and sequence of operations

The conventional (plough-based) cultivation system is based on the complete inversion of the topsoil using a mouldboard or reversible plough, supplemented by a series of pre-sowing cultivation operations. A typical sequence under Polish conditions includes: post-harvest stubble cultivation (immediately after harvest, to a depth of 8–12 cm), ploughing and sowing in autumn (depth 20–30 cm), and in spring – harrowing, harrowing with a harrow, cultivating and sowing [21]. The total number of machine passes across the field ranges from 5 to 8, and sometimes even up to 10, depending on the crop species, soil type and prevailing moisture conditions.

In studies by Golka et al. [9], conducted as part of the POIG project 'Soil cultivation system for sustainable agriculture', it was shown that in a 5-year crop rotation, traditional (plough-based) technology required 19 cultivation and sowing operations consuming 1031 MJ/ha, with fuel consumption of 240 l/ha (in total for the entire rotation, i.e. an average of 48 l/ha per year). By comparison, conservation (no-till) technology required only 8 operations and 423 MJ/ha, with fuel consumption of 106 l/ha (i.e. an average of 21 l/ha per year).

3.2. Energy consumption of individual operations

Ploughing is the operation with the highest energy requirement throughout the entire crop production cycle. The energy

consumption of ploughing depends on many factors: working depth, soil type (particularly particle size distribution and moisture content), working speed, and the technical condition and design of the plough. On lighter soils, fuel consumption during ploughing to a depth of 20 cm is approx. 14–18 l/ha, whilst on medium and heavy soils at a depth of 25–30 cm it rises to 22–32 l/ha, corresponding to an energy input of 780–1135 MJ/ha [8, 15].

Deep ploughing, used periodically to break up the plough pan, requires fuel inputs of 18–25 l/ha at a working depth of 30–45 cm. Cultivation (10–20 cm) consumes 8–14 l/ha, disc harrowing 7–13 l/ha, and harrowing 4–8 l/ha. Harrowing and rolling are the operations with the lowest energy requirements – 2–4 l/ha each [15]. A detailed breakdown of the energy consumption of individual operations is presented in Table 1.

Fuel consumption is also significantly influenced by the tractor's power and its suitability for the implement. Studies show that oversizing the tractor's power by 30–50% relative to the implement's requirements leads to a 10–20% increase in specific fuel consumption due to the engine operating below the optimal load range. Modern tractors with electronic engine control (ECU) and continuously variable transmission (CVT) enable a reduction in fuel consumption of 8–15% compared to older designs [25].

Tab. 1. Energy consumption of basic tillage operations in a conventional system

Tillage operation	Depth [cm]	Fuel consumption [l/ha]	Working resistance [kN/m]	Energy input [MJ/ha]	Productivity [ha/h]
Ploughing with a reversible plough	25–30	22–32	3.5–5.5	780–1135	0.8–1.2
Ploughing with a mouldboard plough	20–25	18–26	3.0–4.8	640–920	1.0–1.5
Deep ploughing	30–45	18–25	2.5–4.0	640–890	0.6–1.0
Cultivation	10–20	8–14	1.5–2.5	285–500	2.0–3.5
Disc	8–15	7–13	1.2–2.0	250–460	2.5–4.0
Harrowing	5–10	4–8	0.5–1.0	140–285	3.0–5.0
Fibering	3–5	2–4	0.2–0.5	70–140	5.0–8.0
Rolling	–	2–4	0.3–0.6	70–140	4.0–7.0

Source: [7, 9, 15]

3.3. Total energy balance of the conventional system

Total fuel consumption over the full conventional cropping cycle, encompassing all operations from stubble cultivation to sowing, amounts to 45–75 l/ha depending on the crop species and soil conditions. This corresponds to a cumulative energy input of 1600–2660 MJ/ha. It should be emphasised that ploughing alone accounts for 45–55% of total fuel consumption for cultivation operations, making it a key factor from the perspective of energy optimisation [9].

It is worth noting that the impact of traditional tillage on crop yields, especially under favourable environmental conditions, is relatively small. Fertilisation, plant protection and the selection of the appropriate genotype adapted to climatic and soil conditions are of much greater importance for crop productivity [29]. This observation is one of the main arguments in favour of simplifying tillage – the high energy input required for ploughing does not translate proportionally into increased yields.

4. No-till farming systems

4.1. Reduced tillage

Reduced tillage involves limiting the number and intensity of cultivation operations whilst abandoning traditional ploughing. Instead of a plough, cultivation units, stubble cultivators or disc harrows are used, which loosen the soil without fully turning the soil. In Polish conditions, multi-operation units (of the 'compact' type) are becoming increasingly popular, combining several operations in a single pass: loosening, crushing, levelling and surface compaction [2].

Fuel consumption in simplified tillage systems is 25–45 l/ha, representing a reduction of 35–50% compared to conventional tillage. Energy input ranges from 890 to 1600 MJ/ha. The main savings result from the elimination of ploughing and a reduction in the number of machine passes across the field from 5–8 to 3–5. At the same time, multi-operation implements allow for an area productivity of 2–4 ha/h, i.e. two to three times higher than with ploughing [9].

Research by Gawęda et al. [7] on the energy efficiency of various tillage systems in a three-field crop rotation confirmed that the agrotechnology involving traditional ploughing was the most energy-intensive. Simplified tillage allowed for comparable yields with significantly lower energy inputs, which translated into a more favourable energy efficiency ratio for production.

4.2. Direct drilling (no-till)

Direct seeding is the most advanced form of conservation tillage, in which mechanical soil cultivation is completely abandoned. Seeds are placed directly into uncultivated soil covered with crop residues using specialised seeders equipped with cutting discs and coulters. According to the definition adopted by the FAO, conservation agriculture is based on three pillars: minimal disturbance of soil structure, permanent ground cover with organic matter, and diversified crop rotation [5, 13].

Fuel consumption in the no-till system is only 5–18 l/ha [9, 15], representing a saving of 60–80% compared to conventional cultivation. Energy input ranges from 180 to 640 MJ/ha. Working time is merely 0.4–1.0 h/ha, which is particularly significant under conditions of short agronomic windows, characteristic of a temperate climate.

At the same time, account must be taken of the additional energy input associated with the use of herbicides, the consumption of which in no-till systems is 15–30% higher than in conventional farming. This applies in particular to glyphosate-based total herbicides used to burn off weed residues before sowing. The full energy balance must take into account the embodied energy in plant protection products, which averages 260–420 MJ/kg of active [17]. Nevertheless, the overall energy balance of no-till systems remains significantly more favourable than that of conventional farming.

4.3. Strip-till

Strip-till technology is a hybrid approach that combines the advantages of no-till farming with the benefits of mechanical loosening of the root zone. In this system, only narrow strips of soil 15–30 cm wide (corresponding to the future rows of plants) are tilled, into which seeds and mineral fertilisers are placed, whilst the inter-rows remain untilled and covered with mulch [28]. This technology is particularly recommended for crops grown in wide rows: maize, sugar beet, sunflower and rapeseed.

Fuel consumption in strip-till technology is 12–22 l/ha – less than in simplified cultivation, but more than in direct drilling. The energy benefits result from limiting tillage to 25–40% of the field area, whilst ensuring optimal temperature and moisture conditions for germination in the sowing zone. Modern strip-till machines enable simultaneous loosening, fertilisation (localised) and sowing, carrying out three operations in a single pass.

In Polish conditions, strip-till is gaining increasing popularity, particularly in maize cultivation on medium and heavy soils, where direct drilling encounters difficulties associated with excessive compaction of the topsoil and delayed soil warming in spring. Strip tillage to a depth of 25–35 cm eliminates these problems, whilst retaining the benefits of mulch remaining in the inter-rows.

5. Comparative analysis of tillage systems

5.1. Summary of energy parameters

A summary of the key energy and environmental parameters of the four main tillage systems is presented in Table 2. The data covers the full cycle of land preparation for sowing, from post-harvest operations to the actual sowing. It also includes indicative cultivation costs based on 2024 price levels and herbicide consumption expressed as an increase relative to the conventional system.

Table 2. Comparison of tillage systems in terms of energy, environmental and economic parameters

Parameter	Plough-based cultivation	Simplified tillage	Strip-till	No-till
Fuel consumption [l/ha]	45–75	25–45	12–22	5–18
Energy input [MJ/ha]	1600–2660	890–1600	425–780	180–640
Number of passes	5–8	3–5	1–2	1
Working time [h/ha]	3.5–6.0	1.5–3.0	0.8–1.5	0.4–1.0
CO_2 emissions [kg/ha]	120–200	67–120	32–59	13–48
Water erosion [t/ha/year]	5–25	2–10	1–5	0.5–3
Cultivation cost [PLN/ha]	800–1,400	450–800	350–650	200–450
Herbicide consumption [Δ%]	ref.	+5–10%	+10–20%	+15–30%

Source: [5, 9, 17].

5.2. Interpretation of differences between systems

Analysis of the data in Table 2 clearly indicates a distinct energy advantage for no-till systems. Direct drilling allows for fuel savings of 37–57 l/ha compared to conventional cultivation. For a farm of 100 ha, annual fuel savings can reach 3,700–5,700 litres, which, at a diesel price of PLN 6.50/l, translates to a cost reduction of PLN 24,000–37,000 per year.

The reduction in CO_2 emissions is proportional to fuel savings and amounts to 72–152 kg CO_2 /ha less in a no-till system compared with ploughing. At the national level, assuming the conversion of even 30% of the 10.5 million hectares of arable land to no-till systems, the potential for emission reductions is estimated at 230–480 thousand tonnes of CO_2 per year. This is a significant argument in the context of Poland's climate commitments under the Fit for 55 package [8].

A separate issue is the impact of individual systems on water and wind erosion. Ploughing leaves the soil exposed and vulnerable to erosive factors, particularly during the autumn and winter months. No-till systems, thanks to the constant coverage of the surface with crop residues, reduce soil losses from water erosion by as much as 80–90% [10]. This is of fundamental importance on loess and silt soils, which are predominant in southern and eastern Poland.

6. The impact of the tillage system on soil properties

6.1. Physical properties

Highlighting the energy aspects of tillage requires simultaneous consideration of the impact of individual systems on the physical condition of the soil. Long-term ploughing leads to the degradation of aggregate structure, a reduction in organic matter content in the surface layer and the formation of a plough pan – a compacted layer at a depth of 25–35 cm, limiting water infiltration and root penetration [20].

Lipiec et al. [20] demonstrated in a long-term experiment on silty soil (Eutric Fluvisol) that conventional tillage (ploughing to a depth of 20 cm) provided the highest areal porosity and infiltration in the 0–10 cm layer, but these differences diminish in the 10–20 cm layer. Importantly, in direct-seeded soils, a network of biopores formed by plant roots and earthworms developed, which partially compensated for the lower structural porosity.

No-till systems, despite higher bulk density in the 0–10 cm layer, are characterised by significantly higher organic matter content and better aggregate stability (Table 3). Long-term studies conducted in Central Europe indicate that after 5–8 years of direct drilling, soil structure self-regulates thanks to the activity of soil fauna, particularly earthworms [22, 25]. Strip-till occupies an intermediate position – loosening in the row zone provides good conditions for roots, whilst undisturbed inter-rows preserve the natural soil structure and water retention.

Table 3. Effect of tillage system on selected physical soil properties (averages from long-term studies)

Soil parameter	Plough cultivation	Simplified tillage	Strip-till	No-till
Bulk density 0–10 cm [g/cm³]	1.15–1.30	1.25–1.40	1.20–1.35	1.30–1.50
Bulk density 10–30 cm [g/cm³]	1.35–1.55	1.30–1.45	1.28–1.42	1.25–1.40
Organic matter 0–10 cm [%]	1.8–2.2	2.0–2.5	2.1–2.6	2.3–3.0
Aggregate stability [%]	35–50	45–60	48–65	55–75
Capillary porosity [%]	38–45	35–42	36–43	33–40
Infiltration [cm/3h]	80–95	50–70	55–75	35–60

Source: [20, 22, 25]

6.2. Biological properties and carbon sequestration

No-till systems promote the accumulation of organic carbon in the topsoil. Lal [18, 19] estimated the global potential for soil carbon sequestration at 0.4–1.2 Pg C per year, a significant portion of which could be achieved by converting plough-based cultivation to no-till systems. Under the temperate climate conditions of Central Europe, the rate of carbon sequestration in no-till soils is estimated at 0.3–0.8 Mg C/ha/year [25].

The absence of mechanical soil tillage also promotes the development of soil microfauna and mesoorganisms. Reeleder et al. [22] demonstrated significant differences in the populations of earthworms ( ), mites and springtails between ploughed and non-ploughed systems. The earthworm population in no-till soils was 2–3 times higher than in ploughed soils, which directly translates into improved soil structure, water infiltration and nutrient availability.

7. Economic analysis of tillage systems

A full assessment of the efficiency of tillage systems requires consideration not only of energy inputs but also of economic aspects. Table 4 summarises the estimated costs of tillage in the three systems for a model farm of 100 ha under 2024 price conditions.

Table 4. Economic analysis of cultivation costs in three systems for a model 100-hectare farm (2024 price conditions)

Cost component	Plough cultivation	Simplified tillage	No-till
Fuel [PLN/ha]	390–488	163–293	33–117
Machinery depreciation [PLN/ha]	180–350	120–250	80–200
Herbicides [PLN/ha]	120–200	140–230	170–300
Labour [PLN/ha]	200–350	100–200	50–120
TOTAL [PLN/ha]	890–1,388	523–973	333–737
Annual savings / 100 ha [PLN]	–	25,000–62,000	45,000–95,000

Source: Own analysis based on market prices for fertilisers, plant protection products and agricultural machinery price lists (as of June 2024).

The analysis shows that the total costs of farming under the no-till system are 40–60% lower than in conventional farming. However, the higher initial cost must be taken into account – a direct-drilling seed drill costs PLN 150,000–450,000, which represents a significant investment barrier. With savings of PLN 45,000–95,000 per year (for 100 ha), the payback period for investment in no-till equipment is 2–5 years, making this technology economically attractive in the long term.

An additional economic benefit is reduced machine wear and lower maintenance costs. A farm practising no-till farming requires a smaller fleet of machinery (no ploughs, harrows or rollers), which translates into lower costs for depreciation, insurance and equipment storage.

8. Limitations and challenges of no-till farming in Polish conditions

8.1. Soil and climatic factors

Despite clear energy and economic benefits, the implementation of no-till systems in Polish conditions presents a number of challenges. In conditions of heavy soils (loam, heavy clay) and a temperate, humid climate, characteristic of much of Northern and Central Poland, direct drilling can lead to excessive soil compaction, a deterioration in the thermal and moisture conditions for germination, and delayed soil warming in spring. Heavy, wet soils covered with a thick layer of crop residues warm up in spring by as much as 2–4°C more slowly than ploughed soils, which delays the sowing date and initial plant growth [25].

A problem specific to Polish conditions is also the high fragmentation of farms (average area of around 11 ha), which makes it difficult to justify the purchase of specialist direct-drilling equipment on economic grounds. A solution could be producer groups and machinery cooperatives, enabling the shared use of expensive equipment.

8.2. Weed control and plant protection

The most significant agronomic challenge of no-till farming is weed control. Abandoning mechanical soil tillage eliminates an effective mechanism for weed control – both by burying their seeds at a depth that prevents germination and by mechanically destroying the root systems of perennial weeds. This necessitates increased use of herbicides, particularly glyphosate [1].

Growing environmental and health concerns regarding glyphosate, as well as emerging forms of weed resistance to this active ingredient, call into question the long-term sustainability of no-till systems based solely on chemical weed control. An integrated approach, combining the rotation of herbicides with different modes of action with the use of catch crops and cover crops, as well as diversified crop rotation, represents a research direction of key importance for the future of conservation agriculture in Europe [14].

8.3. Mental and institutional barriers

In the Polish context, farmers' traditions and habits also pose a significant challenge. Ploughing is seen as the fundamental and 'proper' way to prepare the soil, and moving away from this practice meets with resistance, particularly among the older generation of farmers. The political transformation of the late 20th century and the associated economic changes – high fuel prices coupled with low agricultural commodity prices – did indeed increase interest in simplified cultivation methods, but the full adoption of no-till systems still faces significant psychological and infrastructural barriers [29].

Another significant factor is the lack of systematic institutional support. Unlike in South American countries (Brazil, Argentina, Paraguay), where conservation agriculture is covered by dedicated support and advisory programmes, Poland lacks a comprehensive policy promoting no-till farming. Subsidies for environmentally beneficial practices under the CAP (eco-schemes) only partially offset the risks associated with switching to a new farming system.

9. Prospects for the development of no-till systems in Poland

Despite the limitations described, the prospects for the development of no-till systems in Poland are viewed optimistically. Several factors favour the further adoption of these technologies. Firstly, advancing climate change – particularly the intensification of agricultural drought – means that soil water retention, provided by conservation tillage systems, is becoming an increasingly important factor in crop production.

Secondly, the growing availability of precision farming technologies (GPS-RTK, ISOBUS sensors, soil fertility maps) enables the optimisation of tillage depth, fertiliser and herbicide rates using variable rate application (VRA), which reduces the costs and environmental risks of no-till systems.

Thirdly, innovative agronomic solutions are emerging, such as 'green-till' systems combining direct drilling with the use of catch crops as 'living mulch', which limit weed growth without the need for herbicides. Research into biological methods of weed control, including allelopathic crop varieties, may significantly alter the environmental balance of no-till systems in the future.

10. Summary and conclusions

Based on the literature review, the following conclusions were drawn:

1) Conventional cultivation based on ploughing is characterised by the highest energy inputs, reaching 1600–2660 MJ/ha, with fuel consumption of 45–75 l/ha. Ploughing alone accounts for 45–55% of the total energy consumption for cultivation operations.
2) Simplified tillage systems enable a reduction in energy input of 35–50%, mainly due to the elimination of ploughing and the use of multi-operation implements.
3) Direct drilling (no-till) achieves energy savings of 55–75% compared to conventional tillage, whilst reducing CO_2 emissions by 65–80% and limiting erosion by 80–90%.
4) Strip-till technology offers a promising compromise, combining energy savings similar to those of direct drilling with the benefits of localised soil loosening in the root zone.
5) No-till systems promote the accumulation of organic matter in the topsoil, improve aggregate stability and enhance soil biological activity.
6) The main constraints to the implementation of no-till systems in Polish conditions are: problems with weed control, high equipment costs, delayed warming of heavy soils, and mental and institutional barriers.
7) Economic analysis indicates that the total costs of farming under a no-till system are 40–60% lower than in conventional farming, and the payback period for equipment investment is 2–5 years.

Further research should focus on the long-term assessment of the energy efficiency of no-till systems under diverse soilacross Poland, taking into account the full energy balance (including the energy embodied in plant protection products and fertilisers), the impact on yields over the long term, and economic efficiency from the perspective of the entire farm.

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Productivity of irrigation water and irrigation effect of raspberries grown under optimum irrigation conditions and water deficit

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Summary: *This paper deals with the productivity of irrigation water and the effect of irrigation on raspberries in the Chelopechene experimental field. We examined different regimes, keeping from full satisfaction of daily water needs of crop to irrigation with reduced by 20 and 40% irrigation norms and variant without irrigation*

Moisture optimization in the active soil layer contributes to a significant increase and stabilization of yields, which for the test conditions range from 835 to 1074 kg / dka, with additional yields ranging from 404 to 627, kg / dka or from 47 to 59% on average for the study period. Established productivity irrigation rate is highest in the variants irrigated with a 40% reduction in the optimum norm and varies in units from 13.0 kg. ha -1.mm-1 to 24.0 kg.ha - 1.mm-1, and it is low in the irrigation variants with 100% irrigation rate, with the highest values reaching in the dry year 2000.

KEY WORDS*: PRODUCTIVITY, IRRIGATION WATER YIELD, RASPBERRY, IRRIGATION REGIME, WATER DEFICIT REDUCED RATE.*

Introduction

Obtaining a good effect from irrigation and the most productive use of irrigation water is possible only when applying an optimal irrigation regime, consistent with the requirements of the crops grown. [2, 6, 11].

A number of studies have been conducted on the limiting factor - water in our country [1,7]. Their main goal is to establish the best efficiency of applying different irrigation regimes for irrigation under optimal and insufficient water supply. The effect of irrigation in most cases is determined on the basis of the additional yield obtained from irrigation and the productivity of irrigation water [3, 5, 9, 10].

Getting a good effect from irrigation and the most productive use of irrigation water is possible only when applying an optimal irrigation regime, consistent with the requirements of the crops grown.

The studies conducted so far on raspberry irrigation show that to increase its yields, it is very important to apply water before fruit ripening and during the entire period of their harvest [2,8]. According to the same authors, drought has the greatest negative impact on yield two weeks before fruit harvest and during ripening. When maintaining a limited water deficit in the soil, raspberry yield increases by over 9.6%, and in dry years by 27.6% compared to non-irrigated options [3,4].

The aim of this study is to establish the water productivity and the effect of irrigation on raspberries grown under optimal irrigation and water deficit conditions for Sofia district.

In irrigated agriculture, water deficit can occur not only from physical water shortages, but also from its unavailability due to high prices, energy and organizational problems, limited throughput capacity of the canal network during the dry and hot summer months, emergency situations, etc.

Material and method

The field experiments were conducted in the experimental field of the Pushkarov Institute Sofia during the period 1999 – 2001.

The following irrigation options were tested:

- no irrigation (option 1);
- irrigation with 100% irrigation rate (option 2);
- irrigation with 80% irrigation rate (option 3);
- irrigation with 60% irrigation rate (option 4).

The amount of irrigation rate was calculated according to the formula of (Frecman and Garzoli, 1980).

To monitor the dynamics of soil moisture, soil samples were taken in option 2 (100% a.s.) at a depth of 0 – 60 cm every 10 cm, which were processed by the weight-thermostat method. The soil is leached cinnamon forest, slightly sandy loamy in the arable layer, formed on the base of an old diluvial cone of alluvial materials. It is poorly stocked with nitrogen, moderately rich in phosphorus and well-stocked with potassium. On average, the soil has the following water-physical properties for the 0-60 cm layer: FC (field capacity) = 22.1%, wilting moisture content – 12.3% relative to the weight of absolutely dry soil, bulk density at FC – 1.47 g/cm^3. For the 0-100 cm soil layer, the same indicators have the following values: FC – 21.8%, wilting moisture content – 12.3% and bulk density – 1.50 cm^3.

The soil is suitable for growing raspberry plantations. The scheme of the drip irrigation installation and the parameters of its main elements have been developed under the premise of ensuring uniform distribution of the irrigation rate along the length of the raspberry rows.

The installation is equipped with irrigation wings, double-walled pipelines for drip irrigation type "Agrodrip" with a diameter of 20 mm and a hole for supplying water through 30 cm.

When conducting the experiment, the developed technology for creating the raspberry plantation was used, as well as the agricultural techniques for growing it from the Experimental Station for Berry Crops - Kostinborod. Irrigation was carried out using a drip installation type "Drozbach".

Results and discussions

The productivity of any agricultural crop depends on a complex of factors, the main ones being: the type of crop, its varietal characteristics, the agricultural techniques used, the number of irrigations carried out, the way in which they are applied and, last but not least, the weather conditions [9, 12].

The amount of precipitation during the growing season of the crop (398 mm) for 1999 is 33 mm higher than the average multi-year values, and for the period July - August by 44 mm and characterizes the year as humid (19.2%), and the period July - August is average dry. In 2001, which is characterized as average humid (33.1%), the amount of precipitation in April - September is almost the same as that of the average multi-year series - 358 mm, and in July - August it is 75 mm (Table 1)

Extremely dry with precipitation and temperature security - 98.6% and 3.4% is the year 2000, where the amount of precipitation for the period April - September is 182 mm, which is 50% less than the average multi-year values.

Table 1. Precipitation during the growing season of raspberries (1999 – 2001)

precipitation	Sum of precipitation, mm/m^2			Precipitation factor security, %		
	1999 г.	2000 г.	2001 г.	1999 г.	2000 г.	2001 г.
April – September	398	182	358	19,2	98,6	33,1
Medium-perennial	365	363	362	-	-	-
April – September	152	28	75	7,3	96,6	70,8
Medium-perennial	108	107	117	-	-	-

The months of July and August were particularly dry this year, with the total precipitation amounting to 28 mm, well below the multi-year average of 107 mm for the same period. This precipitation was extremely insufficient for the development of raspberries, which also necessitated the use of a large number of irrigations.

The results of the three-year study show that the number of irrigations and the amount of irrigation rates are determined by the meteorological conditions (precipitation) in individual years. The number of irrigations varies from 12 to 17, and the size of the irrigation rate from 216 to 450 m^3/dka, with the largest number of irrigations being realized in a very dry year (2000), where the number of irrigations reaches 25, and the size of the irrigation rate 450 m^3/dka

When determining the effect of irrigation of raspberries by changing the obtained yield compared to the non-irrigated variant, it was found that in the variant with 100% irrigation rate (optimal) the increase in raspberry yield reaches 60%, and in the variants irrigated with reduced irrigation rates, the size of the yields increases by 54% and 47%, respectively (Table 1) compared to the non-irrigated variant on average for the period of the study (Fig.1).

The results obtained for the yield of raspberries in the years with different humidity levels show the influence of drip irrigation on its size. The largest increase in raspberry yield was obtained in the dry year 2000, which is about three times greater than the non-irrigated variant, and the smallest increase of 247 kg/dka was obtained in the wet year 1999.

When comparing the yields obtained in the irrigated variants with the yield obtained in optimal irrigation, it was found that when the irrigation rate was reduced by 20%, the yield decreased by 11%, and with a greater reduction in the irrigation rate (by 40%), the yield decreased by 23%. On average for the period of the research, the highest productivity of irrigation water, amounting to 4.1 kg of raspberries per 1 m^3 of water, was obtained in the variant in which 60% of the irrigation rate was realized, (Table 2).

Table 2. *Efficiency and productivity of raspberry irrigation water on average for the period (1999-2001)*

Variant	Irrigation rate, m^3/ha	Total yield Y, kg/dka	Additional yield +Y, kg/dka	Compared to var.1, %	Compared to var.2, %	Productivity per m^3
Non watered	-	447	100	100	42	-
100%M	324	1074	627	240	100	3,3
80%M	259	963	516	215	89	3,7
60%M	195	835	388	186	77	4,3

Another important indicator characterizing the efficiency of irrigation is the productivity of the irrigation rate, showing the additional yield for 1 mm of the irrigation rate and with a unit of measurement kg.ha^{-1}/mm^{-1}. The data by variant for all experimental years and the average for the experimental period are presented graphically in Table 3.

Table 3 *Impact of the reduction of the irrigation rate on the additional yield and yield of raspberries, for the region of the Chelopechene Field - Sofia district*

Variants	**1999**			**2000**			**2001**			**average**		
	+Y	**M**	PR	**+Y**	**M**	PR	**+Y**	**M**		**+Y**	**M**	PR
100%M	2470	216	11,4	10090	450	22,4	6230	306	20,3	6263	324	19,3
80%M	1830	173	12,7	8410	360	23,4	5210	245	21,2	5160	259	19,8
60%M	1700	139	13,0	5990	250	24,0	4410	197	22,3	4033	195	20,7

+Y – additional yield, kg/ha; M – irrigation rate, mm/m^2;
PR – productivity of irrigation rate kg.ha^{-1}.mm^{-1}

The effect of irrigation is expressed through the additional yield and productivity of the irrigation rate, with data by year presented in Table 3. It has been proven that under conditions of regulated water deficit, the yield does not change proportionally to the change in the size of the irrigation rate. Therefore, the productivity of the smaller irrigation rate is often higher. For the conditions of the experiment, the values vary from 11.4 to 24.0 kg.ha^{-1}.mm^{-1}, with the highest values reaching in the dry year 2000.

The results obtained for the productivity of the irrigation rate show (Table 3) that it is highest in the variants irrigated with a 40% reduction of the optimal rate and varies over the years from 13.0 kg.ha^{-1}.mm^{-1} to 24.0 kg.ha^{-1}.mm^{-1}, and it is lowest in the variants irrigated with 100% implementation of the irrigation rate.

The constant water deficit during the crop's growing season leads to yield losses that are not adequate to the percentage reduction in the irrigation rate.

The data show that the reduction in raspberry yield is not adequate to the reduction in the irrigation rate. In all cases, the reduction in yield is less than the reduction in the irrigation rate. On average for the study period, when the irrigation rate is corrected by 20%, the yield decreases by 11%, and with a 40% reduction in the irrigation rate, the yield decreases by 23%. In all cases, the reduction in yield is less than the reduction in the irrigation rate

Conclusions

Optimization of moisture in the active soil layer contributes to a significant increase and stabilization of yields, which for the conditions of the experiment are from 835 to 1074 kg/dka, with the additional yield varying in the range from 404 to 627, kg/dka or from 47 to 50% on average for the study period.

Reduced irrigation rates during the raspberry growing season lead to yield losses that are not adequate to the percentage reduction in non-applied water. With a 20% correction of the irrigation rate, the yield decreases by 11% compared to the optimal variant, and with a 40% reduction in the irrigation rate, the losses in raspberry yields reach 22%. The productivity of the irrigation rate is highest in the variants irrigated with a 40% reduction in the optimal rate and varies from year to year from 13.0 $kg.ha^{-1}.mm^{-1}$ to 24.0 $kg.ha^{-1}.mm^{-1}$, and is lowest in the variants irrigated with 100% implementation of the irrigation rate, with the highest values reaching in the dry year 2000.

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